ARMY RESEARCH LABORATORY

High-Mass Launch Capability Development for the U.S. Army Research Laboratory's 50-mm High-Pressure Powder Gun (Range 309A)

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13. ABSTRACT *(Maximum 200 words)*

Documented here are improvements to the 50-mm high-pressure powder gun system in the U.S. Army Research Laboratory's (ARL's) terminal ballistic Range 309A. It was designed for high velocity, achieved by large charge-to-mass (C-M) ratios and a long travel (120 calibers). The goal here was to maximize performance with C-M ratios near 1. This was achieved by a series of incremental improvements to gun and sabot hardware and to priming and propelling charge design. A novel vented sabot described here reduces the incidence of high-yaw shots caused by blowby in a badly worn barrel pushing the sabot forward on a smooth cylindrical projectile. The use of custom-produced propellant has been an integral part of maximizing performance. Achieving optimum performance involved recognizing that even small deviations from the (unknown) optimum configuration of the priming and propelling charge will result in significantly increased pressure, significant to unsafe pressure fluctuations, and significant degradation of velocity. A carefully executed program to optimize the priming and the propelling charge will pay off when maximum performance is desired. Also discussed are good and bad experiences with the hardware as it evolved.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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1. INTRODUCTION

The U.S. Army Research Laboratory's (ARL's) Weapons Technology Directorate (WTD) at Aberdeen Proving Ground (APG), MD, performs basic and applied research into the effect of munitions on military targets. ARL's Range 309A (R309A) is an indoor gun range dedicated to terminal ballistic experimentation. To the extent allowable within a tight firing schedule, R309A practices an informal program of continuous improvements. This report describes a series of changes to the interior ballistics of R309A's workhorse launcher, a 50-mm high-pressure powder gun, and is intended primarily for terminal ballistic gun range personnel. On the other hand, because we use tried and true propellants under carefully controlled conditions, our results have been used from time to time by interior ballisticians as a baseline. Thus, I have gone to great efforts to document the firing conditions as closely as possible.

Knowledgeable interior ballisticians are incredulous at how far behind the state of the art we lag. In the main, this report discusses not improvements, but rather the elimination of problems, the genesis of many of which are now well known to the journeyman interior ballistician. There are a number of reasons for our ignorance, the primary being that it is not our field of expertise. The gun is just a tool. We are not being paid to characterize its performance, and barring a glaring problem, few assets can be dedicated to improvement. Gun systems are often ginned up in-house by range personnel, often taking advantage of surplus hardware. Outside gun suppliers are few and tend to be more knowledgeable in mechanical design than interior ballistics, yet far more knowledgeable in this area than most of their customers. As will be seen here, inadvertent or unrecognized small changes can have major, even dangerous, consequences.

Why aren't problems resolved promptly? Major problems generally beg action. But absent such blatant intrusion, performance well off the optimum is often accepted unquestioningly in many operations. This is indefensible. If performance is not characterized, as should be done during acceptance trials, there is no rational way to judge the margin of safety of the system, much less how much of an increase in performance can be gained, and at what cost. Even when a terminal ballistician has resolved to optimize a gun system, change can be slow. We rely heavily on the interior ballistics community for advice, but changes are expensive and pose the forbidding risk of the unknown. We conservatively adapt to our use only the least risky advances. What an interior ballistician would accomplish routinely in this area if set the task, we at best have to attack piecemeal.

This report, in part, serves as an archival record for our internal use. It has been evolving along with our work. There was never a specific instant at which we could say our task was complete. In fact there will never be. Thus, time was called at one point and a determined effort exerted to wrap up the accumulated knowledge in one package. This report could well be less verbose, substituting more tables and more figures for words, but time did not permit a great editing job. The reviewer suggested I chronicle the changes in a single comprehensive table, a sort of a road map for the reader. This was tried, but foundered immediately due to the number of variables (gun hardware, priming, propelling charge, launch package, etc.), which must be accounted for at each change, and the almost routine changes of conditions imposed by the press of operations. Severing this document into several shorter, easier-to-read reports was untenable because each would have needed about the same mass of introductory material, resulting in a serious net increase in verbiage. The combination here of fine detail interspersed with sweeping generality, spiced throughout with hard-won understanding of some rudimentary principle or the other, may well frustrate the knowledgeable reader, for which I apologize in advance, but the hope here is to reduce the amount of thrashing about by others similarly situated when they set out to tune up their laboratory guns.

This report presents the results of a systematic effort to improve the propelling charge and the push-launch package design for the 50-mm high-pressure gun to maximize muzzle velocity for a massive standardized threat projectile to be used for heavy-armor development work. Working in conjunction with scheduled shots, we started with the lowest package mass judged feasible, changing design details as indicated by results. A novel improvement to the sabot design has greatly reduced the incidence of high-yaw shots from the grossly worn barrel.

The propelling charge design was likewise improved. The approach was to vary propellant web size so that the chamber could be filled with propellant without exceeding the pressure limit of the gun or causing setback of the rod through the pusher plate. Ultimately, launch velocity for the 555-g threat rod exceeded 1,600 m/s, using a 900-g in-bore package mass.

A planned change to simplify the priming proved unworkable, but the results have yielded a further increase in the launch velocity of this massive in-bore package. I intended to eliminate the necessity of custom-loading the priming train in favor of using the promising and readily available M28B2 medium-caliber percussion primer. However, this caused unexpected ignition problems. Custom primer hardware was designed that improved on the old custom-loading scheme, and a systematic study yielded a priming

train recipe that produces a smooth pressure-time (P-T) curve, which, in turn, has resulted in the lowest pressures and the best launch velocities to date for a given charge and in-bore mass.

2. BACKGROUND

R309A is primarily intended for hypervelocity terminal ballistics work. Based on several years' initial operational experience, documented in a report by Silsby, Roszak, and Giglio-Tos (1983), the range and facility were upgraded and returned to service at shot 153. High velocities are achieved by using very high propelling-charge to in-bore-mass ratios at high pressures to launch very light packages from a very long gun. The 120-caliber travel, 50-mm high-pressure powder gun in R309A is capable of launching 50- to 200-g payloads at velocities pressing the limits of modern powder gun performance.

The gun's bore size also makes it uniquely suited within ARL for performing shots with massive projectiles that cannot be accommodated by our family of 26-mm smoothbore lab guns. ARL's Armor Mechanics Branch (AMB) approached us to see if we could launch a length-to-diameter (L/D) ratio 5, 555-g tungsten alloy rod at tank-cannon velocities.

This threat projectile is of Teledyne Firth Sterling X21C, 100 mm long × 20 mm diameter (0.787 in × 3.937 in). Nominal composition is 92.9W-3.4Ni-1.5Fe-2.2Co, swaged 15% reduction in area by the large bar process and strain aged at 500° C. This processing yields a nominal tensile strength of 1,400 MPa (202 ksi), a 9% tensile elongation to rupture, and a hardness of 46 on the Rockwell 'C' scale (HRC 46). Density is nominally 17.71 g/cm^3.

To study improvements in hull-side armor, AMB's practice up to now has been to build full-up heavy-armor packages and attack them with service or surrogate long rod penetrators launched from service or laboratory guns in a large-caliber terminal ballistics range. The outer special armor package remains the same from shot to shot, while the hull-side armor is varied.

In the work reported here, Enderlein (1991) of the Survivability/Lethality Directorate, on a rotational assignment with AMB, dispensed with the special armor package, shooting a short rod that simulates the rear end of an eroded long rod as it exits the (now nonexistent) special armor and attacks the hull-side armor. Use of the short rod in the 50-mm gun is cheap and easy. More importantly, this approach

eliminates the shot-to-shot variability in length and velocity of the remaining rod attacking the hull-side armor that undoubtedly occurs in testing using full-up armor assemblies.

3. LAUNCH PACKAGE

The rod in this program was launched using a push-launch package. The rod rests on a pusher plate of some robust metal, which spreads the acceleration load onto a compliant plastic obturator sealing the gun bore. The obturator and the noninterlocking petal four-petal discarding sabot (which centers and supports the rod laterally in the gun bore) are made of Westlake Plastic's Polypropylux 944A, a void-free, stress-relieved polypropylene-rubber copolymer. The sabot and obturator body are made to a close fit to the (eroded) bore diameter at the rear of the barrel. The last 20 mm of the obturator is cylindrical and is made oversized by 0.3 mm to provide shot-start resistance. Figure 1 is a drawing of a typical launch package used in this effort, which evolved from the initial package tried. (The first packages in this program used a shorter obturator, the sabot only bore on three-quarters of the rod length, and the pusher plate was 5 mm thick.)

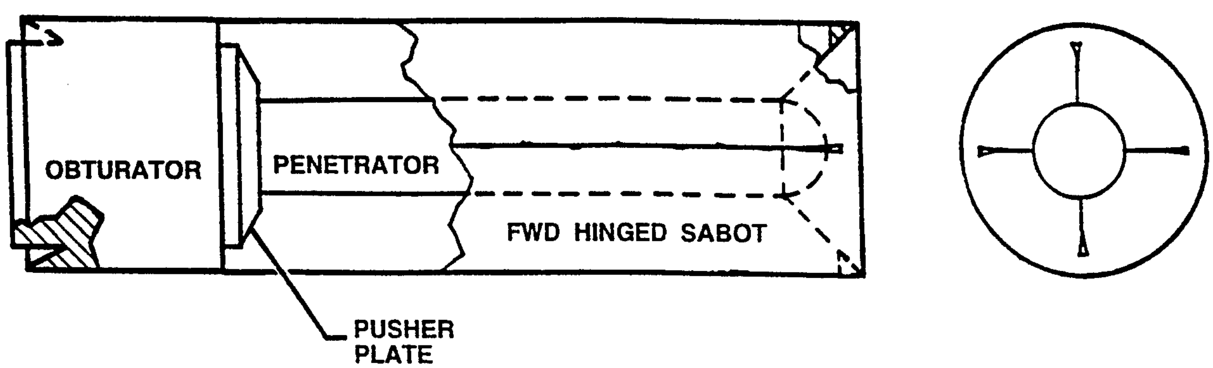


Figure 1. Typical push-launch package. For a 100-mm-long × 20-mm-diameter rod, and with an 8-mm-thick steel pusher plate, this package weighs 900 g.

The pusher plate geometry for the 50-mm gun has been standardized to 40.64 mm outside diameter (OD) (1.60 in). Pusher mass is reduced by relieving the face in a taper of 4:1 on diameter to a 25.4 mm diameter (1.00 in) flat bearing surface. The thickness used (5 mm [0.2 in] or 8 mm [0.3 in]) depends on

the severity of the launch. Various engineering materials are used. To keep in-bore mass down, we worked our way up through a variety of pusher plates (see Table 1), including placing a smaller tool-steel pusher plate on top of the titanium ones first tried. The smaller pusher plate is one of a family of standard designs for our 26-mm nominal bore diameter lab guns and is also used in the 50-mm gun for low-acceleration shots. It is a 25.4-mm-OD × 5-mm-thick right circular cylinder.

Table 1. Pusher Plates

Geometry	Material	Heat Treatment	Hardness (HRC)	Mass (g)
0.2 in × 1.0 in	17-4PH Steel	Precipitation Hardened	44	16
0.2 in × 1.6 in	Ti-6A1-4V	Solution Annealed	38	22
0.3 in × 1.6 in	Ti-6A1-4V	Solution Annealed	38	36
0.2 in × 1.6 in	17-4PH Steel	Precipitation Hardened	44	38
Double Pusher	(0.2-in × 1.0-in Steel on 0.3-in × 1.6-in Titanium)	—	—	52
0.3 in × 1.6 in	17-4PH Steel	Precipitation Hardened	44	64

4. RANGE 309A

4.1 Radiographic Range. The target impact area is very typical of a flash-radiographic terminal ballistic range. The flight is short to minimize yaw growth, and usually no attempt is made to stabilize the projectile. Figure 2 shows the major features of the target room. Looking down into the impact area, the projectile would be traveling from lower right to upper left in the photograph, striking a target that is usually mounted on a table, which can be located anywhere from about 4 to 6 m from the gun muzzle.

The horizontal flash x-ray tubes are in a fully shielded (armored) bay to the left, while the overhead tubes are protected only from below. Flying debris is very effectively confined in the target impact area by a massive piece of armor suspended overhead, projecting from the rear wall. A large thickness of armor plate on the rear wall serves as a target butt to stop a projectile if the target is inadvertently omitted. The striking x-ray film is mounted in a side and a bottom film holder. When the photograph was taken, the bottom film holder was hidden from view by a removable personnel shield that replaces the sabot stripper plate when the range impact area is used for small-arms work.

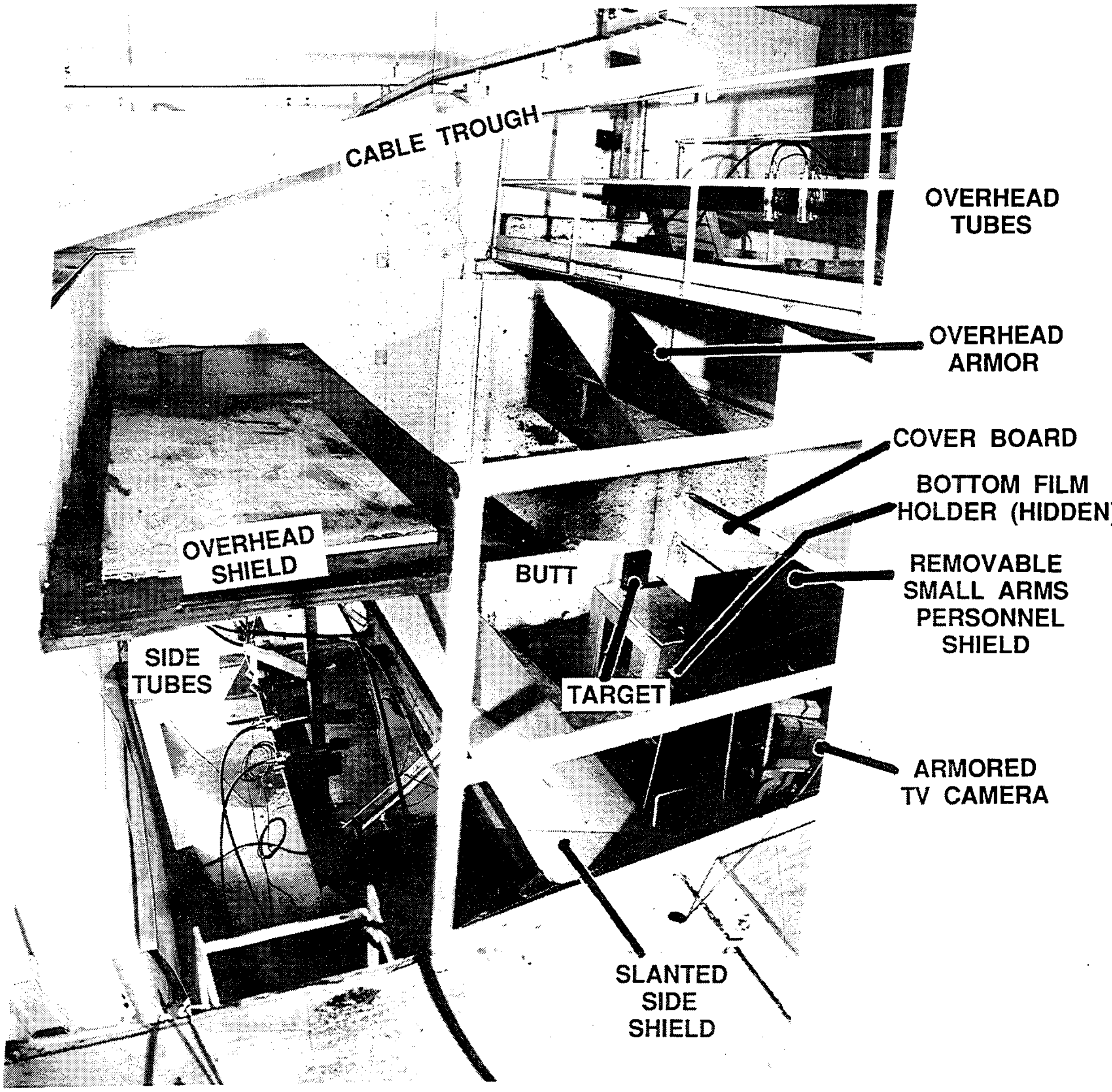


Figure 2. Target room. Shown after shot 277.

The side film holder incorporates a number of notable features, many developed over the years in ARL's smaller-bore Range 110. The holder's rear side is shown in Figure 3. The film holder is mounted in a swing-away wall, allowing a forklift truck to service the target area. A locating pin assures accurate alignment of the wall when in place. Windows a little larger than the x-ray exposure holders are cut into the 1/4-in steel plate of the wall and covered with 1-in (25 mm) plywood to protect the exposure holders

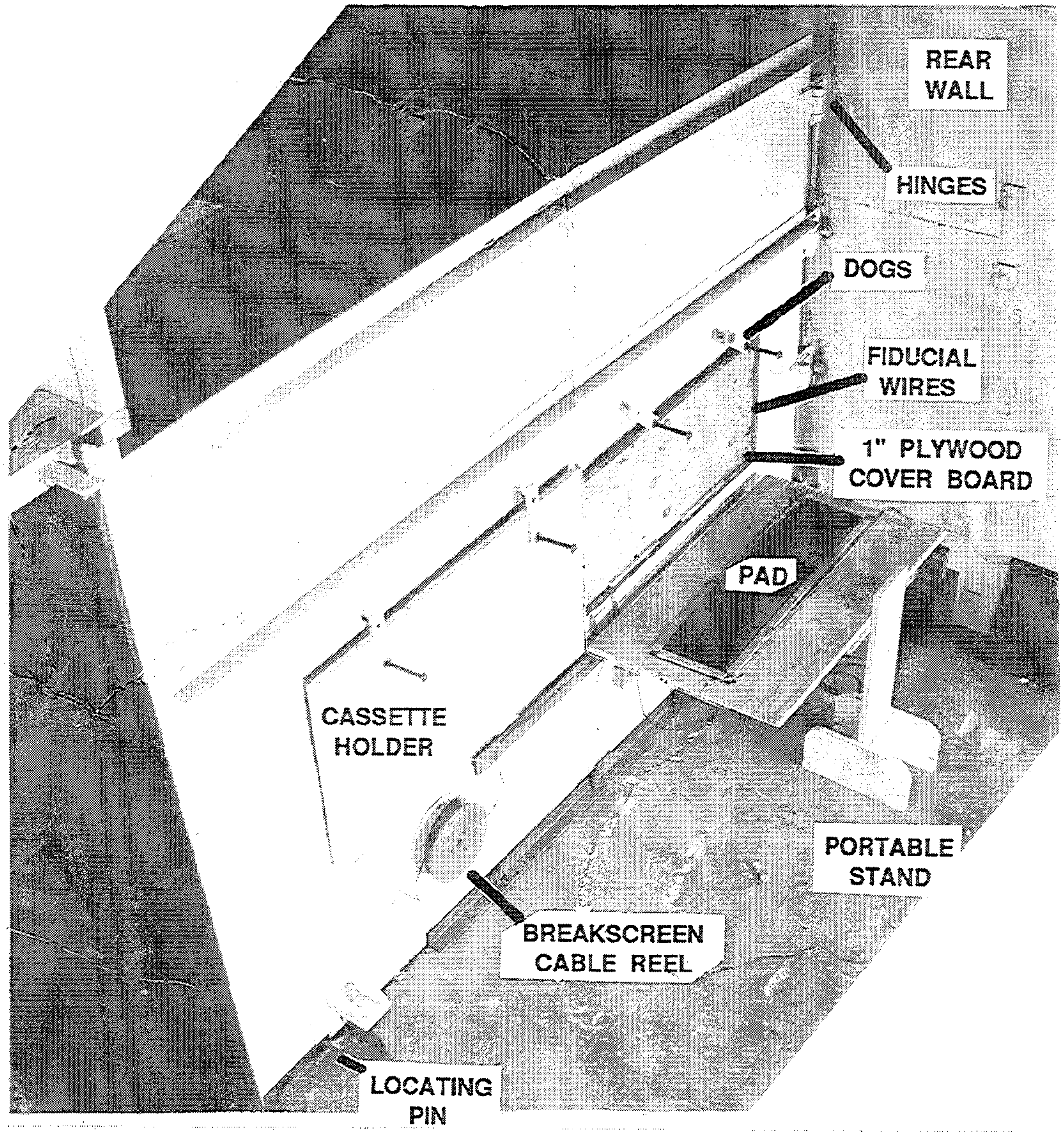


Figure 3. X-ray cassette holder.

against fragments. The fiducial wires that tie the film images into the range coordinate system are permanently mounted on the rear of this plywood that also has clips into which the exposure holders fit. Horizontally hinged doors mount foam pads. When the cassettes are loaded, the doors are forced closed and dogged. The foam compresses the intensification screens against the face and rear of the film in the exposure holders, assuring a sharp image.

Another interesting feature is the continuous reel of cable connected to the break-screen trigger circuitry. Only the standing end is exposed to damage, which is easily repaired by reeling out more cable, cutting off the damaged end, and soldering on new clip-leads.

Not shown is the optical line-of-fire reference system. A fixture, taking the standard 2.2500-in (57.150 mm) OD cylindrical barrel common to various optical tooling components, is mounted on the wall in the rear of the gun room and aligned to the range centerline. An optical alignment telescope placed in the fixture needs no further adjustment to be used to align the gun barrel visually at installation.

Normally, however, a low-energy laser (a laser gunsight) in a concentric mount resides there, for target alignment. Precision apertures just a little bigger than the laser beam are mounted in the breech and muzzle ends of the gun barrel to assure that the laser remains aligned to the gun bore. Only a single person is needed to align the target or other item with the laser spot projected down the range centerline. Retroreflection can be used to square an object onto the beam. The overhead x-ray tubes are aligned by plumbing down to the laser reference beam. A Plane-O-Light (Muffoletto Optical Co., Baltimore, MD), an optical instrument that generates a horizontal (or vertical) plane of laser light, is used to transfer the horizontal reference plane into the shielded bay so as to be able to align the side tubes.

A blast-isolation wall separates the target chamber from the gun room. It is made of 0.5-in (13 mm) steel plate, divided vertically at the gun centerline, and is supported against the blast pressure by a single 2 1/2-in × 2 1/2-in × 3/8-in structural steel angle, about 2 m end to end running horizontally. The large volume of the target room mitigates the blast, and the ample cross-range dimensions make for a very flexible impact area.

4.2 Velocity and Pressure Instrumentation. Muzzle velocity for each shot is measured by either muzzle or striking flash x-ray instrumentation typical of many terminal ballistic facilities. Figure 4 is a photograph of the firing console area showing the x-ray and other instrumentation. The flight distance to the target is so small that velocity decay is insignificant. The velocity determined between the two x-ray stations at which the most reliable positions and times are obtained is reported as both the muzzle and the striking velocity.

The trigger signal for the flash x-rays is usually generated by the projectile interrupting a conventional break-screen circuit. Starting at shot 190, a second triggering means was installed for the muzzle x-rays.

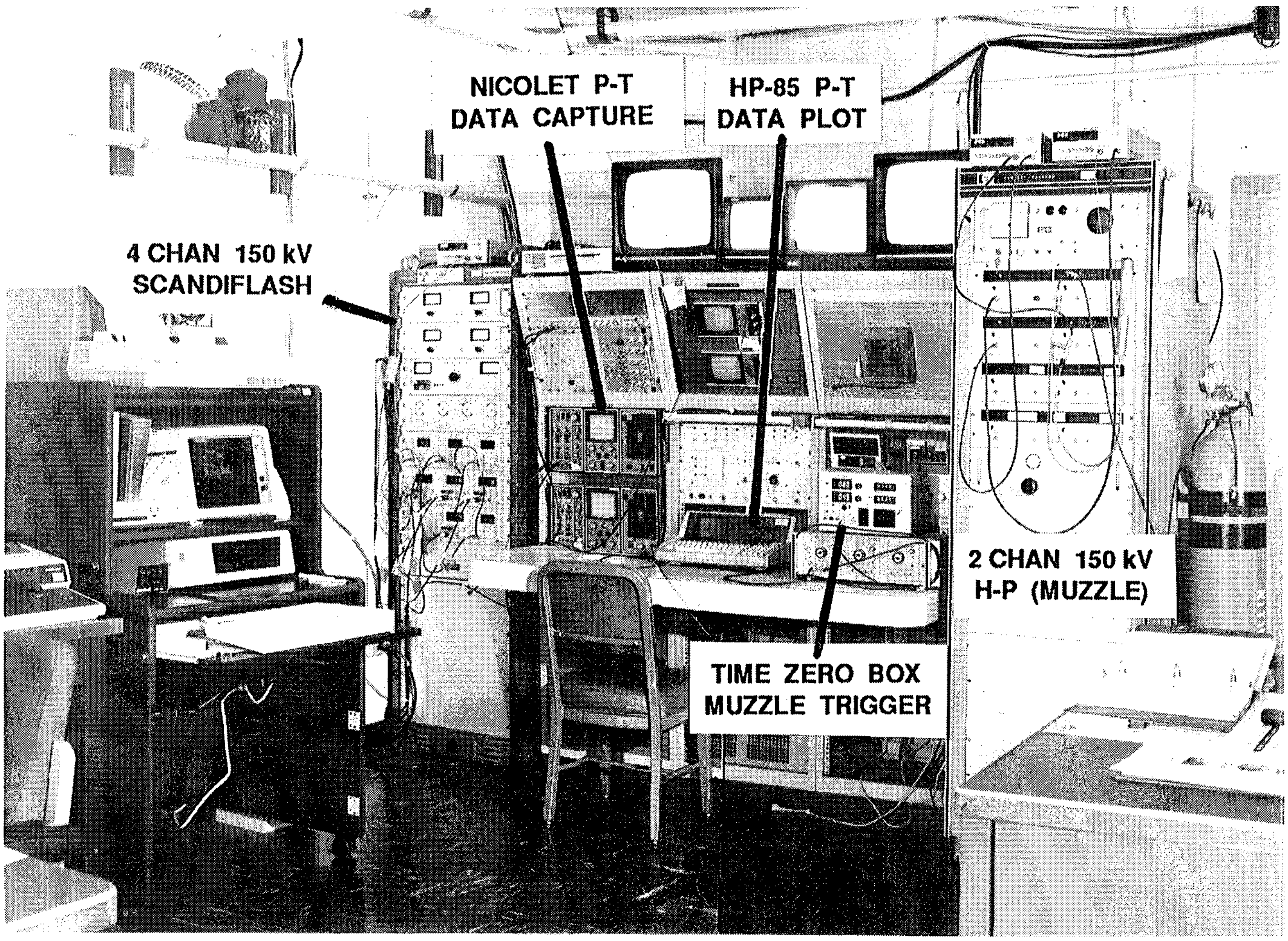


Figure 4. Control room, R309A. Shown after shot 277.

A BRL-designed device called a "Time Zero Box" analyzes the raw voltage-time (V-T) signal from a pressure gage mounted in the muzzle blast field (Clay et al. 1992). Detection of the precursor air shock preceding the package out of the gun muzzle starts a preset delay counter. At the end of the interval, circuitry to detect the air shock when the obturator clears the gun muzzle is gated on. When this indication of shot ejection occurs, a triggering signal is generated that starts the delays for a pair of orthogonal 150-kV flash x-ray channels used for muzzle radiographic coverage.

Two independent types of gun pressure instrumentation are used, copper crusher (CC) and piezoelectric gages. Two M11 CC gages are placed at the rear of the propelling charge on opposite sides of the igniter (spit) tube at the face of the plug breech. These are heavy-walled devices closed to pressure except for a piston of known area on one end that rests on an annealed copper ball supported on an anvil. Pressure on the piston crushes the copper ball until the ball's bearing area becomes large enough to support the load. After the shot, the device is opened, the ball removed and replaced with a new one, and the height of the crushed ball measured. The pressure is read from a table of crushed height vs. pressure, calibrated to the lot of balls used.

The gun is equipped with six piezoelectric gage ports. One is located close to the rear of the chamber, while a second one is in the tapered throat at the forward end of the chamber. Four more gage ports are located at approximately equal intervals up the barrel. Gage output is sampled at a high rate (typically every 5 μs) by Nicolet 2090 digital recording oscilloscopes. The raw voltage vs. time data from two channels is multiplexed into adjacent locations in memory, and then is written to disc for record. While data from up to six channels can currently be captured, we normally only record breech face and chamber throat V-T traces. A BASIC computer program (by Jim Spangler, formerly of R309A) writes the V-T data from a scope into the memory of an HP-85 computer and outputs it to a thermal-pin printer as two curves of voltage vs. a common time (channel number) baseline.

The V-T traces contain a wealth of data. However, only that data which is useful for our purposes is information in the mathematical sense. The CCs are extremely reliable. We have lost only a few CC measurements in our years of operation. For this reason, it is the CC breech pressure data that is used for the pressure vs. propelling charge mass (C) database for predicting future gun performance. The peak voltages of the piezo gage V-T traces are multiplied by the appropriate individual gage constants (which constants vary somewhat from nominal from gage to gage), to obtain peak piezo pressures as an independent check on the CC pressure values. As a terminal ballistic facility, the sole reason for our seeking P-T data is as a preventive measure. By monitoring the response of the P-T traces to changes in operating conditions, measures can be taken to reduce the likelihood of pressure waves and the accompanying extreme overpressure which can burst the breech end of a gun.

A nonparametric estimate of the quality of the propellant burn is obtained by observing the severity or absence of disturbing features in the V-T or P-T traces. The quality is coded using a scheme elucidated by the author and his associates in the earlier work cited (Silsby, Roszak, and Giglio-Tos 1983),

reproduced as Figure 5. The discs containing the raw V-T data were archived in case further analysis should be needed. The equipment became so worn out, however, that the data can no longer be recovered, and the thermal printer output is the only usable record extant.

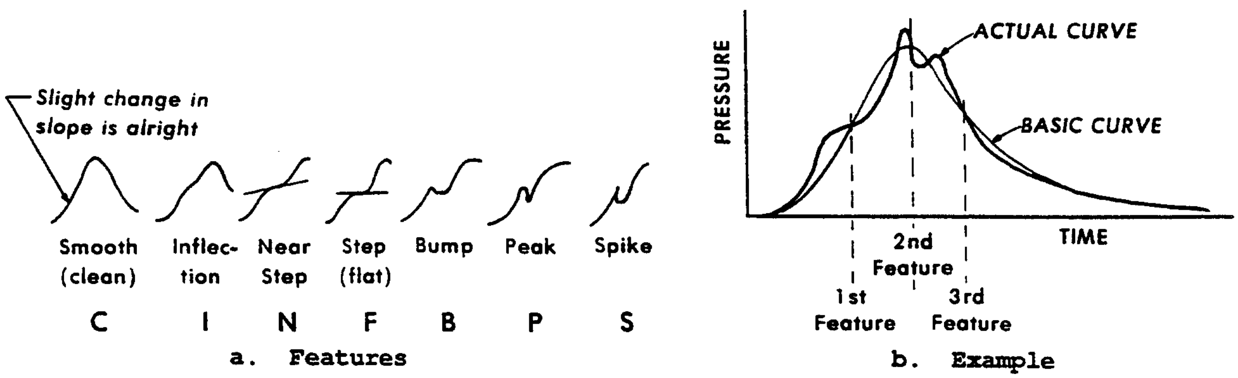


Figure 5. Nonparametric coding scheme for P-T trace quality (a), with example (b). Nomenclature is the same whether the feature occurs on the rising or falling limb. In the example, the curve would be characterized as "inflection, peak, bump" (IPB in the data tabulation).

A good P-T curve rises and falls smoothly. When irregularities are observed, they generally appear to consist of a periodic function of considerably higher frequency and lower amplitude added to the basic (clean) curve. The result is an irregularly rising and falling trace. When present, any very high-frequency components are ignored. The coding scheme for the burn quality consists of characters related to the severity of the individual major features, ranging from "C" for clean to "I" for inflection (a change in slope) through "S" for a spike. The number of characters is related to the number of major features observed.

When P-T curves at both the breech face and chamber throat are obtained, the presence of pressure waves (discussed in later sections) can be demonstrated unequivocally when the two traces show similar features about 180° out of phase.

5. EVOLUTION OF THE 50-mm GUN

The 50-mm smoothbore laboratory launcher in R309A is shown in Figure 6. It was designed and supplied to ARL by the University of Dayton Research Institute (UDRI), entering service in 1981. It has

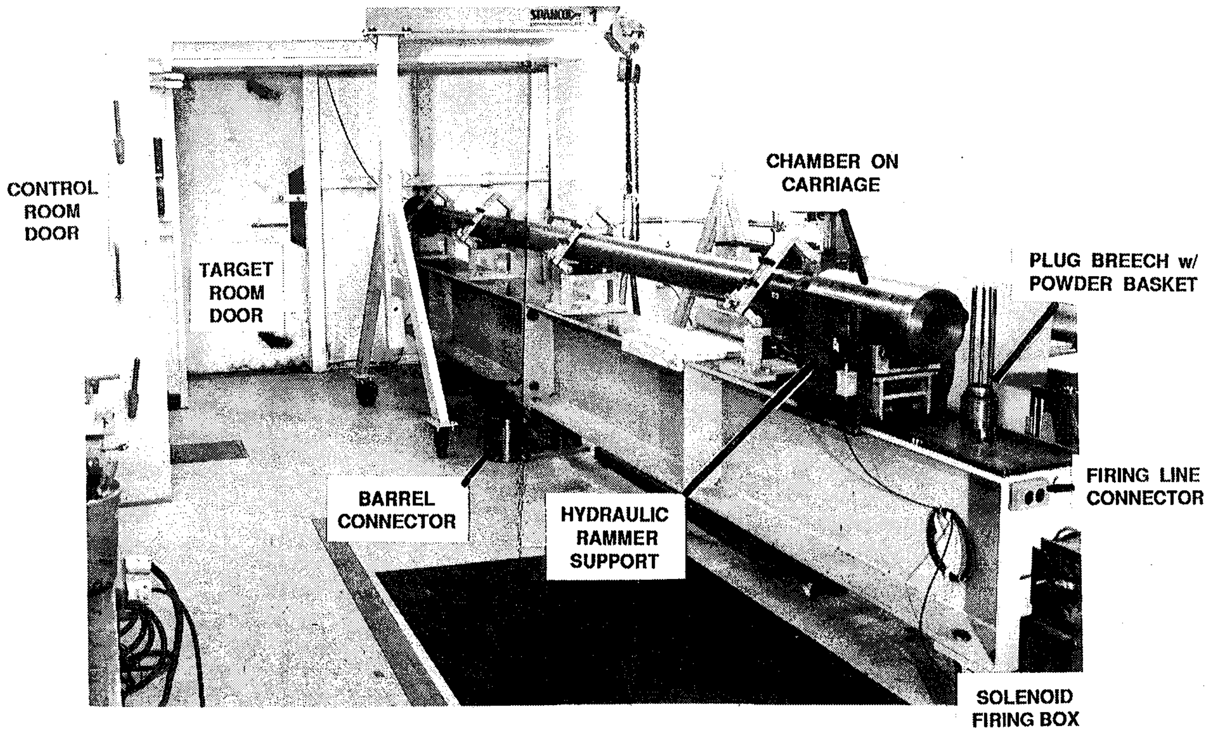


Figure 6. 50-mm gun in gun room, R309A.

subsequently been slightly modified by ARL. Nominally, its powder chamber is 3 in (76 mm) inside diameter (ID) × 12 in (300 mm) long from the breech face to the beginning of a 40-mm-long (1.5 in) double taper reducing the chamber to the gun's bore diameter, nominally 50 mm (2 in). The rear of the projectile is normally seated about 25 mm forward of the end of this taper, flush with the rear face of the tube (barrel) proper (RFT).

In the period reported here, the barrel was in two 10-ft lengths, each resting on two roller mounts. In Figure 6, the barrel has been disconnected in the middle, and the connector is sitting on the floor. The barrel projects through a blast isolation wall, with its muzzle about 1 m into the target room, which is a former blast chamber (Figure 7). A thrust collar on the muzzle engages two hydraulic snubbers, whose integral springs return the gun to battery after the shot. The gun typically recoils about 20 mm.

5.1 Loading Procedure. To load the projectile (the launch package), the breech plug is unscrewed out of the chamber and the chamber unscrewed from the barrel. The chamber is run back on its wheeled carriage. See Figure 6. A hydraulic jack is dropped into the rammer supports and the package rammed home into the rear of the tube. The propelling charge is then loaded, the chamber screwed on to the rear of the launch tube, and the breech plug screwed shut, in an order depending on the breech-end hardware in use at the time.

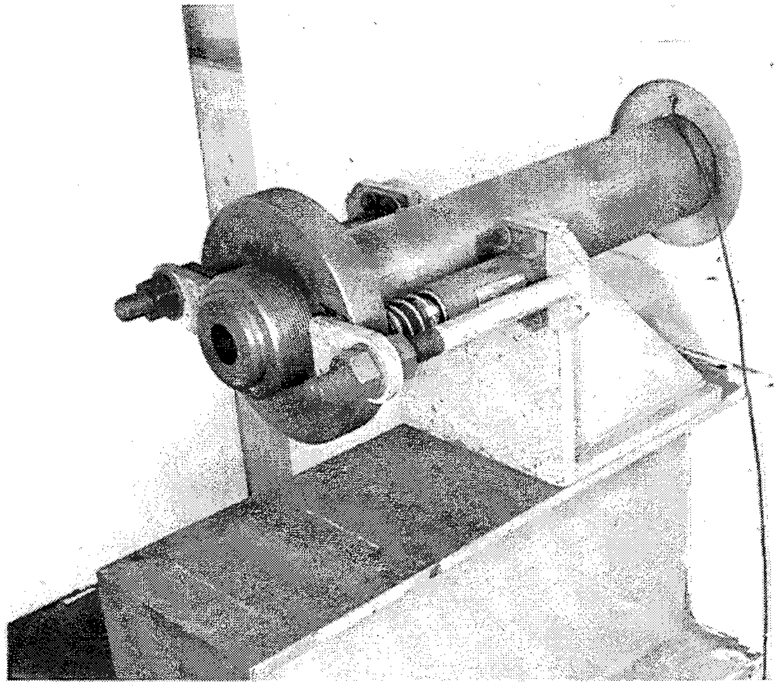


Figure 7. Muzzle end view of 50-mm gun projecting into the target room, showing the recoil mechanism.

5.2 Plug Breech and Obturating Hardware. We are constantly striving to make improvements that will increase safety, boost productivity, improve the workflow, and reduce costs. Various improvements to the priming train, propelling charge geometry, and breech obturating means have evolved with experience.

5.2.1 Original UDRI Breech-End Setup. The major change to the UDRI gun was to redesign the breech plug and breech-end obturating hardware. The original UDRI plug breech was a straightforward acme-threaded plug, flat on the chamber end. The breech plug had a boss projecting to the rear, chambered for a 300 H&H Magnum cartridge case serving as a primer. The priming case was held in place by a screw-on cap breech with an integral solenoid firing system. The breech end was obturated with a free-floating, double knife-edge seal ring. See Figure 8.

Early-on, the original crew in R309A had developed a loading procedure in which the propelling charge was contained in an annular powder bag, drawing/part number (PN) 90032. This was just a cylindrical cloth bag with a cloth tube sewn up its center to accept a long igniter tube. The bag was slipped over a piece of 3/4-in copper pipe, filled with the appropriate propelling charge, and sewn shut.

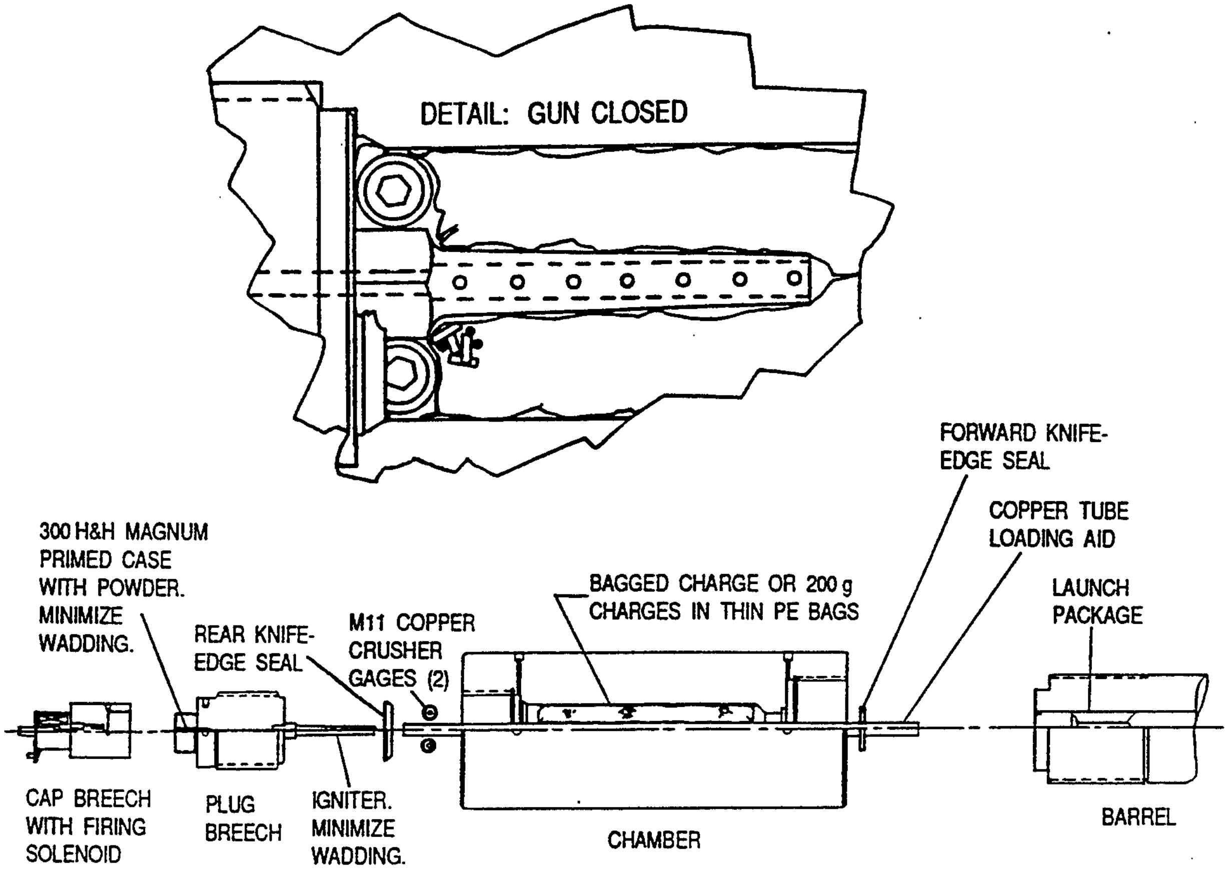


Figure 8. Original UDRI breech-end setup. (PE is polyethylene.)

This assembly was inserted into the chamber from the rear. Two CC gages were placed to the rear of the powder bag and the UDRI breech-end knife-edge seal inserted. The loaded igniter tube was screwed into the breech plug, then inserted in the copper pipe, and the breech plug and spit tube assembly screwed home as the copper pipe was withdrawn forward. The bagged charge was then seated to the rear with a wooden tamper. The chamber was then screwed onto the rear of the launch tube.

Attempting to keep all of the loose components in place as the breech plug was screwed in required great dexterity and some luck. Worse yet, there was no positive indication that the seal was properly seated. One day our luck ran out and the seal ring cocked. The ensuing gas leak welded the seal ring to the chamber and to the breech plug. The plug had to be machined out, destroying it. Fortunately, a replacement of improved design had been made.

5.2.2 ARL Breech Plug With Knife-Edge Seal Obturating Plate. I had improved on the UDRI design, in which the breech plug face itself is exposed to powder gases, and hence to heat checking and deterioration. The new design decouples the function of applying the axial force to contain the chamber pressure from the function of obturation by having the plug breech push on a separate breech seal plate, simplifying the loading operation. See Figure 9.

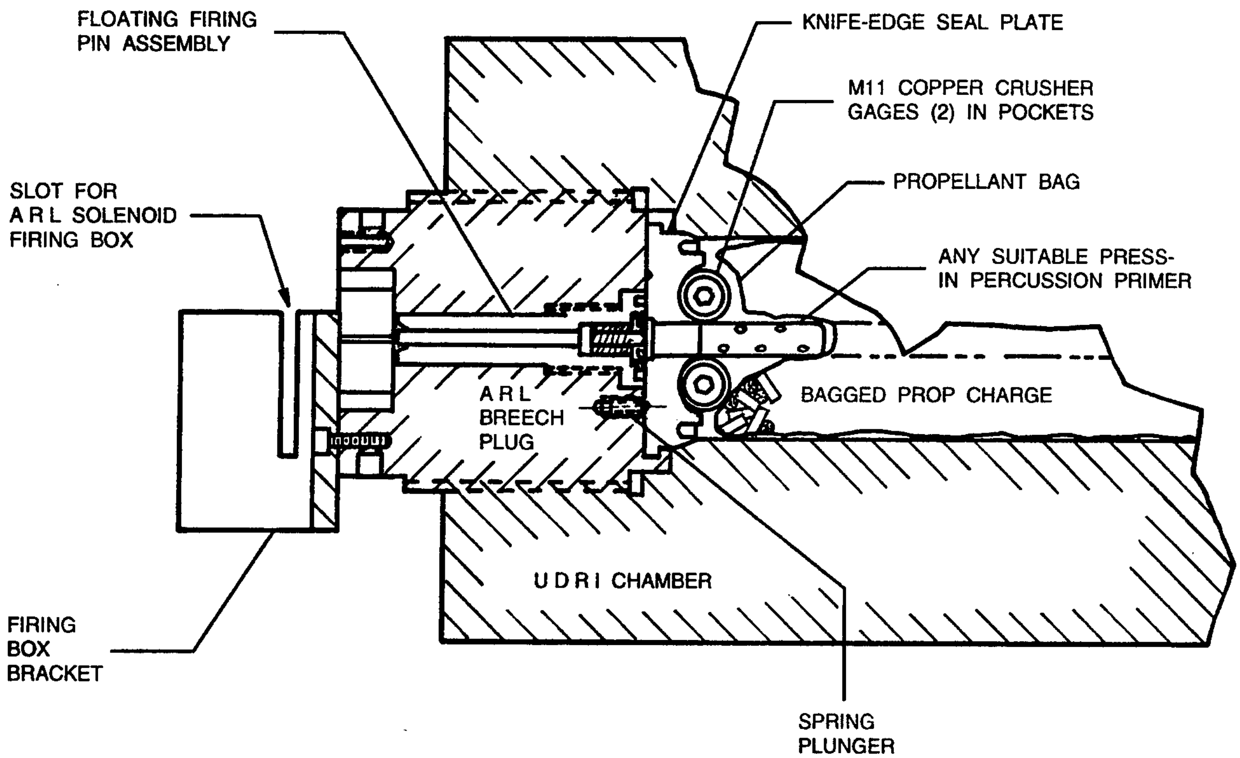


Figure 9. ARL breech plug and breech-end setup for UDRI knife-edge seal.

This ARL breech plug differs from the UDRI breech plug in several ways. It contains a floating firing pin assembly designed to be used in common with ARL's newly-introduced 40-mm lab gun system. Both the 40-mm and 50-mm guns are designed to be fired by a removable solenoid firing box used in common with a number of other gun systems at ARL. Heavy lugs on the rear of the breech plug serve a dual function. They can take a bracket for mounting the firing solenoid, and they permit the use of a 1 in (25-mm) square bar to break open the breech if heavy force is necessary. The thread root profile on the breech plug is relieved more than that of a standard acme thread, and the root radii are rounded in a high-stress design that provides more flexibility in the threads. This spreads the axial load over more threads, reducing the chances for progressive failure under extreme axial load.

The replacement breech plug is designed to accept a breech obturating (seal) plate that mimics the stub end of an obsolete U.S. M23A2 57-mm cartridge case. When used in conjunction with the ARL breech seal plate, the ARL breech plug is interchangeable with the UDRI breech plug and free-floating, knife-edge seal. The rim of the ARL seal plate engages a clip on the face of the new plug breech, and is retained by a detent. As does the 57-mm case, the seal plate accepts a press-in, medium-caliber percussion cannon primer.

Over the years, a whole series of these primers have been fielded, which fit into a primer pocket of the same design in cartridge cases ranging from those for the very obsolete 37-mm towed gun to the currently fielded 105-mm howitzer. About one labor-hour per shot can be saved by using a standard item instead of assembling our priming train from scratch. More importantly, by eliminating the handling of bulk energetic materials and components in favor of using a proven assembly, safety is increased.

5.2.3 ARL Breech Plug With Hexaseal Obturating Plate. The seal plate designs initially incorporated an integral knife-edge seal. A number of evolutionary changes to improve handling were made (not discussed here) but suffered from repeated leaks. We sought the advice of Dave Schade and his associates (1991) at the FMC Corporation's Hollister Range, which mounts a Physics Applications Inc. (PAI) (Dayton, OH) 50-mm gun similar to ours. For obturation, he recommended we switch to a PAI Hexaseal design. Hal Swift and his associates at PAI (1991) kindly provided me the design parameters, which I adapted to our obturating plate design. The Hexaseal has worked very well, once that we learned to lock up the breech plug in heavy metal-to-metal contact.

During the same interval, several changes to the propelling charge design were reflected in the seal plate assembly design, so that until recently, a bagged charge was contained in a basket. The entire seal plate assembly is then handled much like a cased propelling charge. See Figure 10.

The Hexaseal is a thin ring seal comprising a compliant gasket, a steel floating ring, and a second compliant gasket, trapped in an annular space of square cross section. It is designed to use O-rings as the gaskets. Neither Viton (Dupont) flouro-elastomer O-rings nor an O-ring of fluorinated ethylene-propylene (FEP) encapsulating silicone rubber has been altogether satisfactory, although the fault might be in my dimensioning and tolerancing of the components.

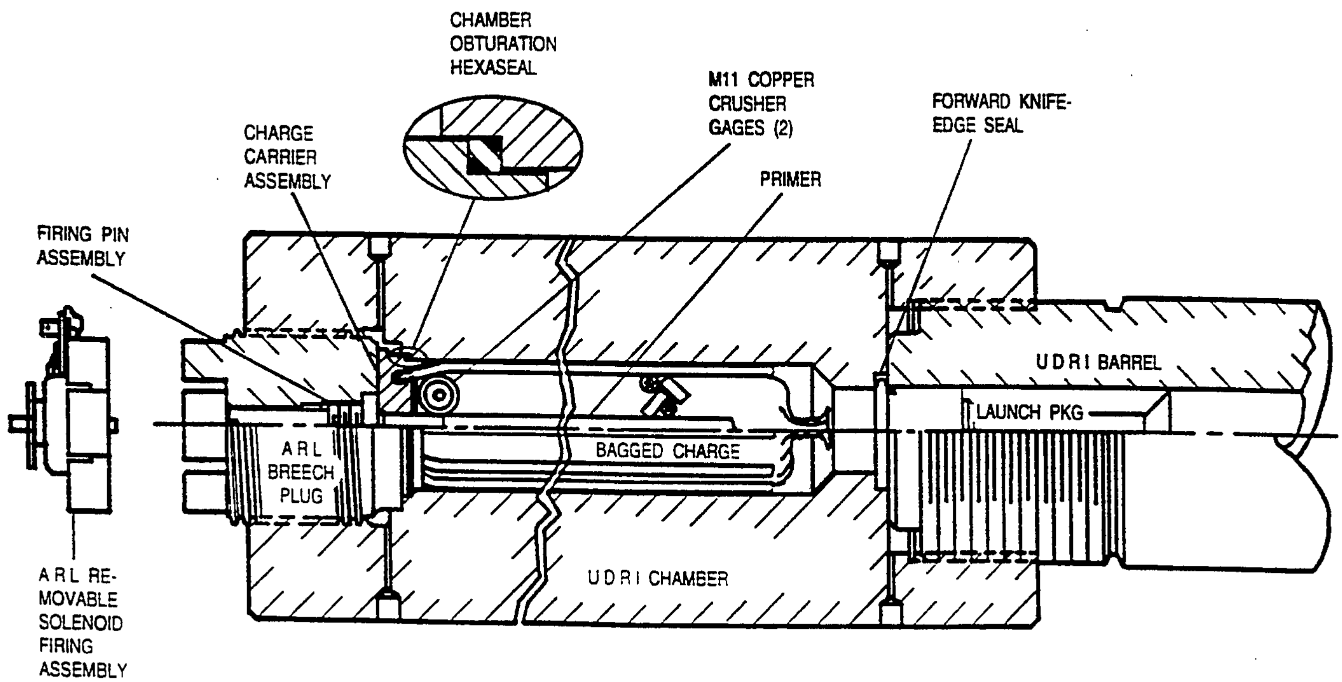


Figure 10. <u>ARL breech plug and obturating plate setup</u>. After shot 277.

O-rings seal by rolling slightly as they seat. This action, combined with extrusion into the slight gap in the seal assembly, causes a hair-thin ring of material to shred off on each shot. This has not caused any loss of obturation during the shot, but the seals must be replaced frequently. The silicone rubber encapsulated FEP O-rings also fail by the silicone core bursting through the encapsulant after 5 to 10 shots. We have found that a tetragonal cross-section polytetraflouroethylene gasket (PN 93021) provides long and reliable service.

Historically, when the concept of a breech-loading weapon was introduced, breech obturation became the primary engineering challenge, met by using the metallic cartridge case. Subsequent to this program, a series of gas leaks across the Hexaseal, caused by debris in the seal area, necessitated reworking the chamber seal area several more times. Each time the seal surface is remachined, the breech face advances further into the chamber, reducing available powder volume. We switched to a custom-made metallic cartridge case to obviate this trend. The cylindrical chamber was opened up on a very slight taper, starting 0.25 mm oversize on diameter at the seal surface and running out to nominal diameter over 150 mm. A 150-mm overall length stub case was made of 17-4PH steel, precipitation hardened to its nominal maximum strength, HRC 44.

The details of the case are specific to this system and are not reported, but the essence of the design should be generally applicable to similar gun systems. Mimicking the design of the service 57-mm case, the stub case wall increases in thickness uniformly from 1.0 mm at its mouth to 1.5 mm where it intersects a 13-mm radius blend into the case base. The case base is 20 mm thick, with a primer pocket, matching the design of the seal plates. A 0.025-mm diametral clearance on top of small unilateral tolerances assures as small a radial clearance with the chamber as practical. Due to the extremely small taper, this results in a very large axial clearance between the case wall in its normal seating position and the chamber. A ring at the base completely fills the void in the chamber forward of the extraction rim on the case which was formerly occupied by the series of Hexaseals.

Obtaining an initial gas seal at the case mouth is critical. This is achieved by the simple expedient of wrapping a strip of ordnance tape (duct tape) around the inner periphery of the case, half on the case and half hanging out. A second strip of ordnance tape, about 15 mm wide, is laid onto the projecting tape, sticky side to sticky side. Initial gas pressure pushes this seal against the chamber wall, preventing gas pressure from getting behind the case wall at the mouth, permitting it to expand and seat firmly.

Blowby around the primer in the loose seat is eliminated by placing a generous ring of hot glue on the cardboard disc at the base of the powder bag and immediately pressing it home over the primer with a piece of 1-in plastic pipe. We have put approximately 50 shots on the existing stub case without it failing, probably the result of the very small radial clearance.

5.3 <u>Priming</u>. The influence of the priming and the propelling charge composition and geometry cannot be neatly separated from each other and from other causal agents, but for the discussion of the gun evolution, I will treat each in its own subsection here. We initially followed UDRI's practice, using a commercially available version of spherical propellant used in military 20-mm ammunition, Winchester (Olin) WC870 Ball Powder (TM), also marketed as Hodgden H870. We then switched to custom-produced granular 7-perforation (7-perf. or 7P) M30 propellant in a number of small web sizes. At the same time, the geometry of the propelling charge in the chamber changed from time to time in response to events. I will discuss priming first.

In the original UDRI ignition scheme, a short (125-mm intrusion) spit tube (shown earlier as a component in Figure 8) filled with black powder was screwed into a plug breech that accepted a 300 H&H Magnum rifle cartridge case. The cartridge case was intended to be loaded with about 1 g of any pistol

or shotshell powder. The chamber was loaded with the main propelling charge in 200-g increments in polyethylene sandwich bags and fired with a solenoid-driven floating firing pin assembly in a cap breech.

Misunderstanding the loading instructions when the gun was first installed, the original crew persisted in loading the priming cartridge to the neck with powder (about 3 g). This grossly overpressurized the ignition train, resulting in severe fluctuations in the P-T traces, accompanied by swelling of the UDRI spit tube, which burst on shot 8. We are not experts in interior ballistics. As a routine policy, we seek advice from experts in ARL's Propulsion and Flight Division (PFD) regarding performance of our laboratory gun systems. Geene (1980) and Deas (1981) of PFD provided much help in the initial period of operation.

Unaware that the loading procedure was at fault, the original range crew conveyed the impression to the PFD personnel with whom they consulted that UDRI's recommended loading procedures were being followed. Geene and Deas first attributed the P-T irregularities to the igniter tube geometry and the very small grain size of the 20-mm spherical propellant.

They made a number of recommendations, all of which were adopted. A full-length spit tube promotes near-simultaneous ignition of the propelling charge over its full length (central ignition). This was implemented by making 12-in (300 mm) intrusion spit tubes from longer ones salvaged from spent M80 military electric primers. They suggested switching to using a small-webbed M30 propellant (discussed later) whose burn duration was better matched to our ballistic cycle. They suggested using Benite strands (a black powder-40% nitrocellulose (NC) igniter composition [Encyclopedia of Explosives and Related Items 1962]) in the spit tube. The strand geometry permits deep penetration of the igniter charge by the hot gases from the primer and booster charge, and Benite is especially well suited for igniting M30 propellant (Kirkendall 1984). In R309A, the strands are usually broken to nearly the full-length of the igniter tube.

When the thin-walled military igniter tubes continued to burst from internal pressure, a heavy-walled full-length igniter tube was tried beginning at shot 22, in an attempt to prevent rupture (Figure 11). The first was 270 mm (10 1/2 in) overall length, PN 81006-1, later changed to 325 mm (12 7/8 in) overall length (300-mm intrusion, PN 81006-2). Though these changes greatly reduced the pressure fluctuations, something was still clearly wrong.

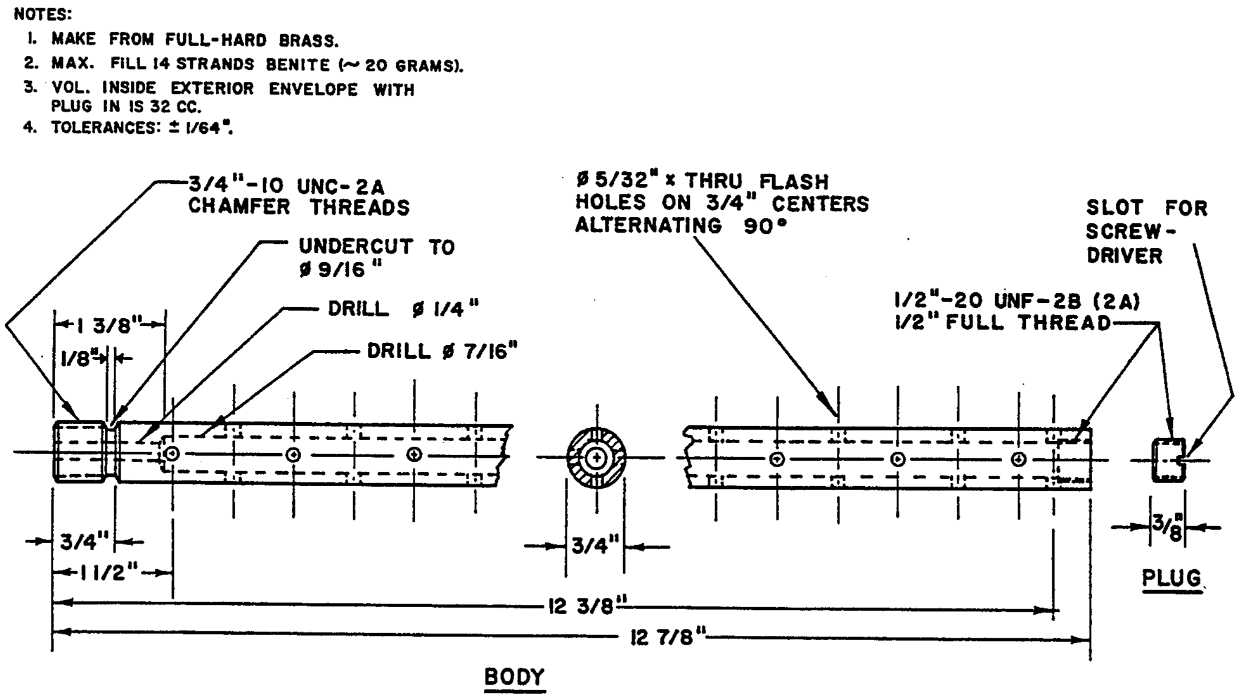


Figure 11. ARL heavy-walled, full-length igniter tube, PN 81006-2. PN 81006-1 was 10 1/2-in overall length.

Upon being assigned oversight of R309A at shot 49, I discussed the matter with Deas (1981), Geene (1981), and White (1981) of PFD. After a thorough review of the loading data, priming was pinpointed as the root cause of this self-inflicted problem. Three figures showing the response of the system to these early ignition changes are instructive.

The individual vertical scales on the P-T curves here and throughout the report differ slightly from the nominal value shown due to variations in individual piezo gage sensitivities. Figure 12 compares the P-T (actually V-T) traces of the 20-mm spherical propellant as it responds to being overdriven with a short spit tube.

Due to equipment deterioration, the older raw Nicolet digital storage oscilloscope (DSO) data archived on the discs became unrecoverable, so it is not practical to easily convert the individual V-T graphs to P-T data and subtract the two to show the oscillations in pressure in the chamber. It does not take a trained eye, however, to see that, in the first case, the pressure gradient in the chamber would be rearward for a short while, while in the second case, the difference signal would oscillate radically, a classic hydrodynamic pressure wave.

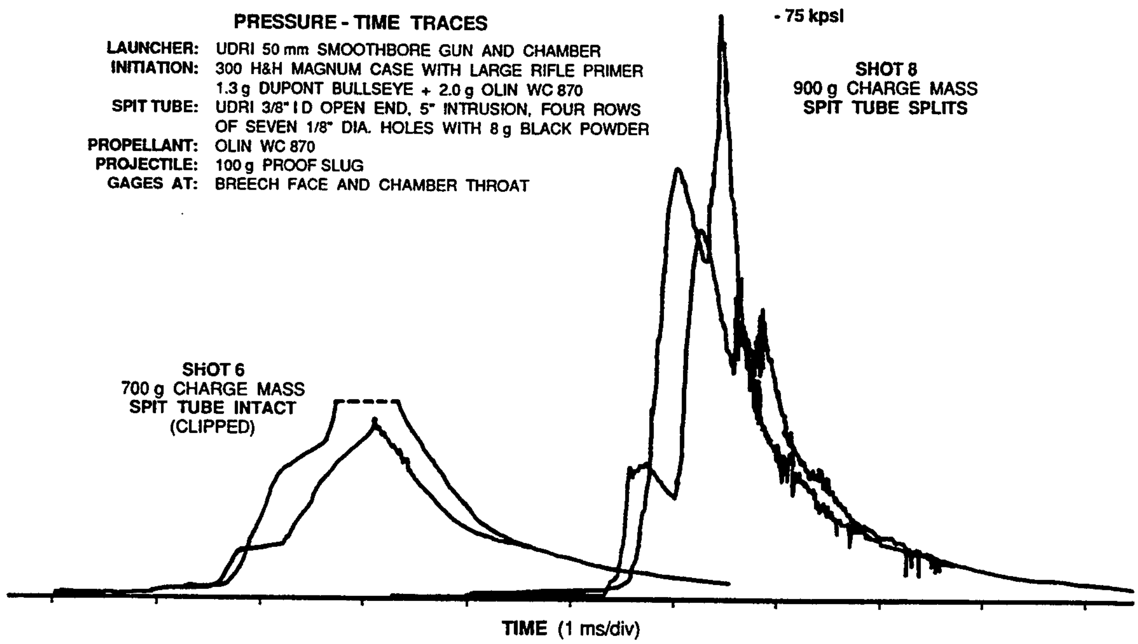


Figure 12. <u>Pressure vs. time traces resulting from gross overpressure of the ignition train and a short spit tube in 20-mm spherical propellant</u>. Loading conditions are typical of routine operation. Note that the rise of the forward trace proceeds the rise of the breech-face trace.

Chase Scientific Company (Aptos, CA) DSO boards installed in a PC have since replaced the Nicolet general-purpose instruments. Each of these very affordable low-end products captures, stores, manipulates, and outputs two channels quite adequately. As with the Nicolet DSOs, one board is modified to output a master signal, so that all other boards can be slaved to provide a common time base.

Compare P-T traces with those seen when a full-length spit tube is used, Figure 13. Also note the dramatic improvement in the performance of the M30 propellant compared with that of the spherical propellant. (However, the M30 response is not always as smooth as this under these loading conditions, as will be seen a bit further on.)

Deas (1981), Geene (1981), and White (1981) judged the bad P-T traces to be indicative of base ignition of the granular propelling charge, exacerbated by the ullage (free volume) in the forward end of the chamber. Such pressure waves are seen as being caused by the propellant gases being accelerated by a high axial pressure gradient, then impinging on a barrier, either the shot base or the breech face. As the gases slow to a stop relative to the barrier and stagnate, the pressure and temperature rise locally. The rise in pressure causes a rise in burning rate in smokeless powders, causing a rise in gas generation rate and a consequent additional local rise in pressure. If the pressure rise is enough to overcome the

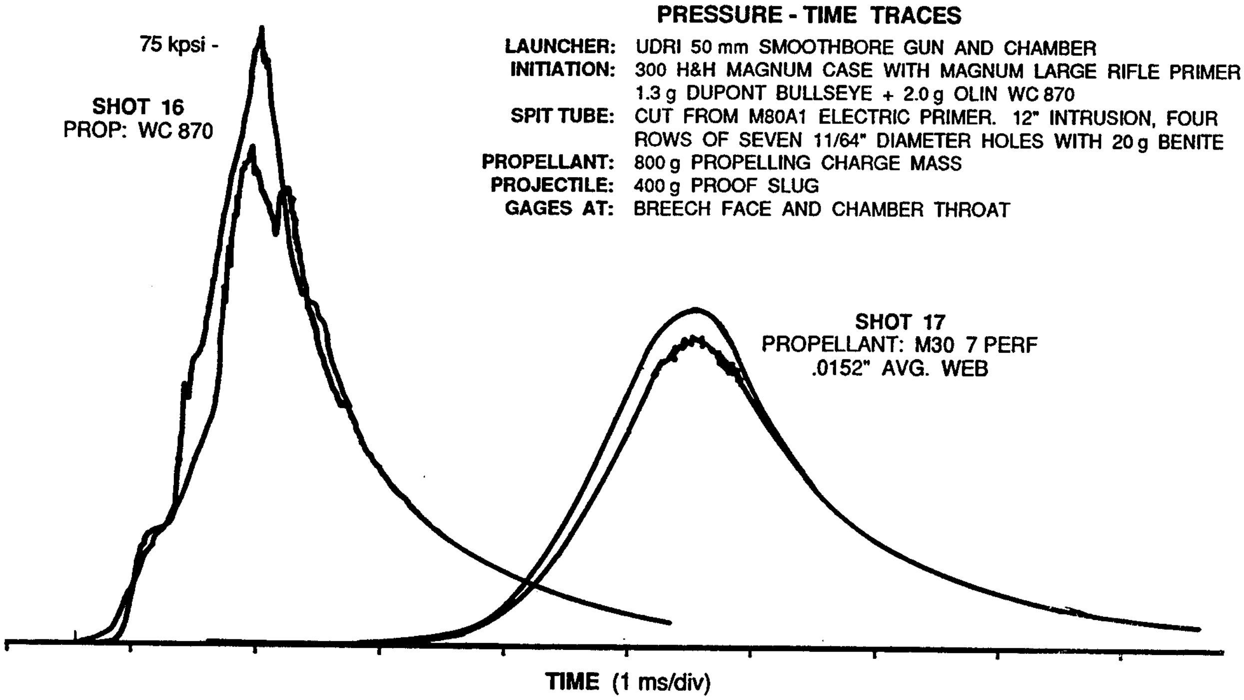


Figure 13. Pressure vs. time traces resulting from gross overpressure of the ignition train with a long spit tube. Compare the response of the 20-mm spherical powder with that of the 0.0152-in-web, 7-perf. granular M30 propellant under these typical loading conditions.

flow-imposed pressure gradient, the gas is then accelerated in the opposite direction. The burning propellant grains are entrained and can be broken on impact with each other or with the chamber walls. This unprogrammed generation of new burning surface can cause additional localized pressure increases.

In Figure 14, three P-T traces show the difference in performance of the 20-mm spherical propellant and the custom small-webbed M30 under relatively mild overdriving (1.5-g pistol powder), and the deterioration in performance of the M30 when the priming charge was increased to 3.0 g.

Classic troubleshooting procedures were used to determine the optimum priming recipe for the small-webbed M30 propellant. This approach is to observe the situation and form a hypothesis regarding the source of the problem. The hypothesis is revised as indicated by the results of systematic experimentation. The problem is isolated by a process of devising a test that divides the system into two compartments and determines in which compartment the fault lies.

The portion of the system exhibiting the fault is then likewise treated, and so on, dividing the system into finer and finer compartments until the suspected cause is found. Measures are taken to fix the fault,

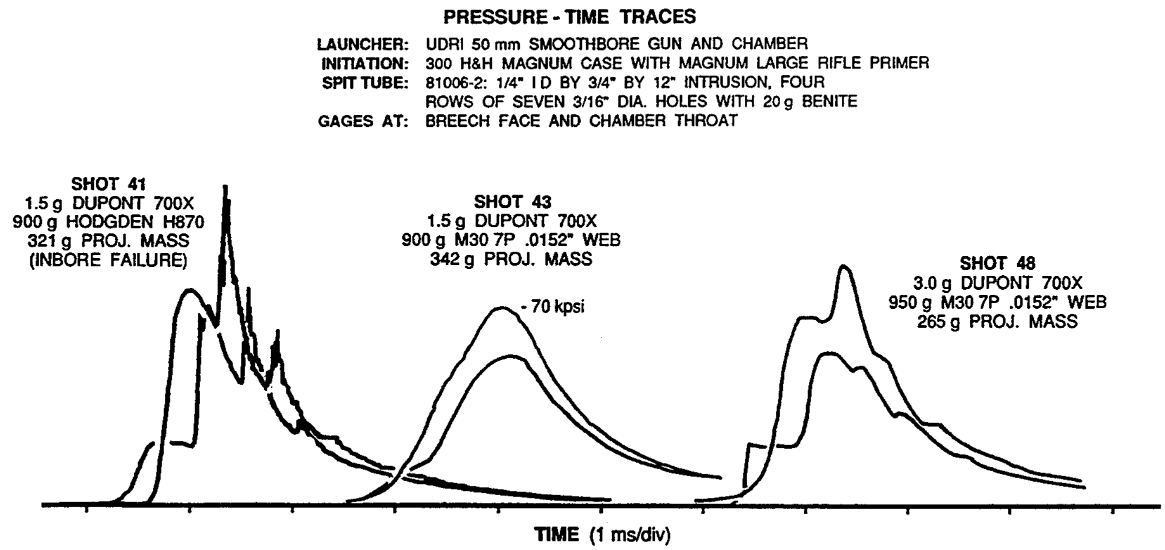


Figure 14. More pressure vs. time traces compared. The improvement in switching from 20-mm spherical powder to subscale M30 with 1.5 g of priming powder can be made to disappear by increasing the priming charge to 3 g.

and the system run through its paces. If the fault disappears, the suspected cause is then intentionally reintroduced. If this causes the fault to reappear, that cause is nearly certain to be the actual cause. Though intermittent faults and the interaction of several causes can complicate the procedure, the problem is usually solved rapidly.

I sought a priming charge that would not swell the igniter tube, would deliver a smooth P-T trace, and would use just enough priming to assure sensibly prompt ignition (we have no instrumentation that will measure ignition delay). Having more than ample data for high-loading masses of priming powder, I started at the other extreme on shot 50, looking for maximum change in response. Pushing a 208-g in-bore mass with 1,000 g of propellant, I used 0.5 g of Dupont HiSkor 700X pistol powder to light 11.42 g of full-length strands of Benite in the 300-mm intrusion heavy-walled custom igniter tube (PN 81006-2).

There was an ignition delay of approximately 1 s, but the igniter tube did not swell, and the P-T traces were clean. The conditions on shot 51 duplicated those of shot 50 except the priming was 1 g of 700X and 20 g of Benite. Ignition was sensibly prompt, the igniter tube did not swell, and the P-T traces were clean. For shot 52, the same ignition train was used, but the in-bore mass was increased to 563 g, driven by 950 g of subscale M30. The response was the same as that of the previous shot.

Filling the igniter tube with approximately the same volume of an inert material having about the same compressibility and geometry as the Benite igniter material (the wooden sticks from long cotton swabs) demonstrated the cause of the erratic ignition traces with the higher pistol-powder loads. Three loadings of the priming cartridge case were tried on an empty chamber: 3, 2.5, and 1 g of 700X.

On the first, the wooden sticks were completely jammed forward, blocking the last four pairs of flash holes and leaving no material in the rearward part of the tube. On the second, the wooden sticks were violently driven forward and shattered, blocking some of the forward flash holes, but the material was not consolidated the way it was with the 3-g charge. On the 1-g shot, the sticks remained more or less well-distributed along the tube, with no flash holes either completely blocked or completely open, although a number of the sticks were partially shattered and blown forward, nearly blocking the forward six pairs of holes.

Subsequent experience when the Benite charge has failed to light confirms that the behavior of the wooden sticks, which break up and pack, simulates the behavior of the Benite, though the wood is tougher. The most plausible hypothesis for the genesis of the pressure waves resulting from overdriven priming in this system is that unburnt Benite blocks the forward flash holes early in the ignition. Stagnation of the booster-propellant gases on the plug causes vigorous local ignition of the main propelling charge, consistent with the diagnosis of Geene, Deas, and White (1981).

I ultimately settled on a priming recipe of 0.75 g of pistol powder in the 300 H&H Magnum case and 20 g of Benite in the 300-mm intrusion heavy-walled custom igniter tube. This delivered reliable ignition of the M30 propellant, up to the time when circumstances suddenly forced us to change breech plugs, and hence the ignition scheme.

Based on our favorable experience with the custom priming system with the long spit tube, my intent behind redesigning the breech plug was to take advantage of the readily available military M28 percussion primer, which has a 250-mm-long (10 in) spit tube, and is in current production for the 105-mm howitzer. We began using it on shot 169, under conditions duplicating those of the last shot with the custom long spit tube, a successful launch using a double pusher. We experienced a setback failure. The pusher thickness was increased to 8 mm and the load dropped, for a successful shot.

With a slightly higher propelling charge mass, we had two more setback failures. The initial rise on the P-T curve appeared steeper than with the custom tube. In one case, the spit tube was blown off the end of the primer stock. There was clearly something wrong with the M28 primer and its use was discontinued.

After the UDRI breech plug was destroyed, we had no immediate means to return to using the hand-assembled priming train with the long spit tube, which had worked so successfully in the past. The only primer we could lay our hands on was the M38B2, whose igniter tube was only 54 mm (2 1/8 in) long. We tried one on shot 173 and experienced an ignition delay. We were still using the powder bag with an integral sleeve up the center, PN 90032, and speculated that we were getting poor contact with the propellant.

The powder charge was carefully tamped against the primer on the next shot and no ignition delay occurred. An AISI S7 tool steel pusher plate, hardened to HRC 55, was tried on this shot and broke up, leaving me to wonder if the primer or the pusher plate were at fault. The propelling charge design was changed commencing at shot 175 to assure more intimate contact with the propellant.

We continued to use the M38B2 primer until we received a supply of MK22 L/70 primers at shot 196. These have a marginally longer spit than the M38B2. Performance was good for a number of shots, during which interval we made several improvements to the propelling charge geometry. Then, two shots in a row displayed disturbing features, and we decided that a long igniter tube was essential, precipitating a study which culminated in the development of a priming recipe for a custom primer based on M28 hardware. These studies are discussed as separate sections.

5.4 <u>Propelling Charge</u>.

5.4.1 Propellants Historically Used. On the advice of Geene (1980) and Deas (1981), a custom-produced, small-web, 7-perf. M30 propellant was tried early-on to replace the 20-mm ball propellant. Bruce Burns of PFD kindly supplied some in three web sizes thought to span the optimum for this system, 0.34 mm (0.0132 in), 0.39 mm (0.0152 in), and 0.44 mm (0.0172 in) (lots RAD-E-29, RAD-E-30, and RAD-E-31, respectively). The unusually small web sizes of these granulations had been designed to model the M68 tank cannon's interior ballistics at one-third scale using the obsolete 37-mm cannon (Burns 1981). The propellant had been custom-manufactured by the Radford Army Ammunition

Plant, Radford, VA (Hercules, Inc., operating contractor). Propellant description sheets, where available, for the M30 propellants used during this study are included in the Appendix.

In the first year of operation, the mid-sized propellant was used exclusively (RAD-E-30, 0.015-in web). As seen earlier, this resulted in a marked decrease in the degree of severity of the P-T trace disturbances, masking, for a while, the effect of the inherently bad priming.

5.4.2 Increased Effective Web Size. The high-mass program started at shot 160, using 0.46-mm (0.018 in)-web, 7-perf. M30 propellant. It became clear that an even larger web size should deliver better performance by lowering the peak pressure. While we did not have any such propellant on hand, the performance of the desired web size could be achieved by using a blend of propellants with identical chemical compositions but differing web sizes (Kirkendall 1984).

Sporadically, starting at shot 181, an increased effective web size of 0.64 mm (0.025 in) was used to evaluate its performance. This was usually achieved by blending equal masses of 0.46-mm custom and 0.81-mm (0.032 in) surplus M30 military propellant. The performance was as expected. The blends sometimes also included a significant fraction of 0.86-mm (0.034 in) and/or 1.07-mm (0.042 in) web, 19-perf. M30 propellant, which has a very large grain. The effect of this large a granulation did not seem to cause any deviation from the performance predicted by the law of mixtures. At shot 249, the use of 0.64-mm (0.025 in) web became standard.

Blending propellants of differing composition should be avoided, as Kirkendall of PFD (1984) cautions. Adding even small amounts of a propellant with a higher flame temperature to another propellant can cause a catastrophic increase in pressure over what the mixture law might predict. Because of the large increase in burning rate with temperature of smokeless powders, the higher flame-temperature propellant in the blend boosts the burning rate of adjacent lower flame-temperature propellant unpredictably.

5.4.3 Charge Geometry. Bore wear was getting excessive at the beginning of shot travel, so beginning at shot 141, the projectile was seated with its base about 75 mm forward of the RFT. To keep the chamber volume constant, an aluminum displacer of equivalent volume was made that fit over the spit tube at the base of the chamber. It was made with a pair of slots that held the two CC gages as a loading aid. In one instance during this effort (shot 165), the displacer was omitted.

The ignition delay associated with the forced use of the short M38B2 primer prompted Bill Edmanson, the lead technician at R309A, to design a setup to assure intimate contact between spit tube and propellant beginning at shot 175. A short cartridge made from phenolic tube, a bit longer than the spit tube, was filled with about 300 g of bulk propellant and held in place with a layer of masking tape. A powder bag held the rest of the propellant, pushed rearward into firm contact with the base increment.

Ignition was prompt with this charge geometry. However, the P-T traces showed a significant change in slope on the rising limb. They tended to have a rather steep rise, which then reduced somewhat. Near the peak, the rise tended to be steep again. The shape suggested a smooth trace to which was added a single cycle of low-amplitude fluctuation. The shape suggested a slight delay in communicating fire from the rear to the forward charge. Such a slight delay in flame propagation should result in a lower peak pressure than that which would be experienced with a unitary charge. Indeed, we were able to launch the high-mass package at a slightly higher propelling charge mass, and hence velocity, than with the unitary bagged charge configurations.

On the other hand, shot-to-shot differences among the P-T traces suggested considerable variability in the time it took to light the forward charge. One would expect to occasionally experience prompt flame propagation between the two parts of the charge, resulting in higher peak pressures. Thus, a wider margin of safety above the average pressure experienced at a particular loading would need to be allowed when using our two-piece charge, eliminating any gains.

This concern prompted Mr. Edmanson to devise an inherently safer unitary charge design. It was introduced at shot 233 and remains in current use (we are now at shot 874). The igniter tube is admitted directly into the interior of a single full-length powder bag. The central sleeve of the powder bag used earlier is eliminated, and a cardboard disc is hot-glued onto the bag's now-open end. The disc has a central hole forming a tight fit on the spit tube.

A primer is pressed into the primer hole in the breech seal plate and the powder bag slid into the charge basket and pressed onto the primer spit tube. Two M11 CC gages are carefully placed on opposite sides of the spit tube in the bottom of the bag, with their axes parallel to the breech face. The bag is loaded with the appropriate charge of bulk propellant and stitched shut. On most shots after this design was implemented, the change in slope observed on the rising limb of the P-T traces was reduced. Periodically, though, several small peaks would show up, so that the worst traces with the unitary charge

were worse than the worst traces with the two-part charge. The responses of these charge designs to various primers are discussed later.

Initially, to accommodate the bagged unitary charge, I designed a thin perforated brass charge basket, integral with the seal plate, made from a 57-mm cartridge case. The basket looked much like a recoilless-rifle cartridge case, with a close pattern of 5/8-in-diameter holes all over to prevent gas behind the basket wall from collapsing it.

Unexpectedly, at shot 246, gross pressure fluctuations occurred. The edges of the holes in the basket were badly battered during the shot. This explained the pressure glitches occasionally observed. I had designed a propellant grater—an invitation for disaster. The basket design was immediately changed to the series of axial rods seen earlier in Figure 10. It gave quite satisfactory service until replaced by the stub cartridge case base used to overcome breech obturation problems. The various components discussed previously, used during the high-mass charge development work, are shown in Figure 15.

5.5 <u>Interior Ballistics</u>. A single piezoelectric gage was being used at the pressure tap closest to the breech face at the beginning of this development effort. When we began recording P-T traces suggesting pressure waves, a second piezo gage was installed at the head of the chamber to compute differential pressures. To find a starting propelling charge mass and predict the expected breech pressure, we used empirical fits to the database of acceptable (representative) shot performance.

For limited ranges of velocity around existing data, multiple linear regression is adequate for modeling the charge mass vs. in-bore mass vs. velocity relationship. If shots at the desired velocity with similar in-bore masses had not been fired before, with the first several shots in a series, the charge mass usually would need to be adjusted to achieve the velocity requested within about ±20 m/s. Based on the simplistic assumption that velocity is proportional only to the total energy contained in the propelling charge, usable extrapolations to well outside the domain of existing data can be made by relating velocity to a fitted constant parameter times the square-root of the charge-to-mass ratio. However, a much better fit can be obtained by allowing the exponent on the charge-to-mass ratio to vary as well. Figure 16 illustrates this.

Breech pressure is adequately modeled for a constant in-bore mass by a fitted parameter times the propelling charge mass squared. Figure 17 shows the result of fitting this model to the database current at the time.

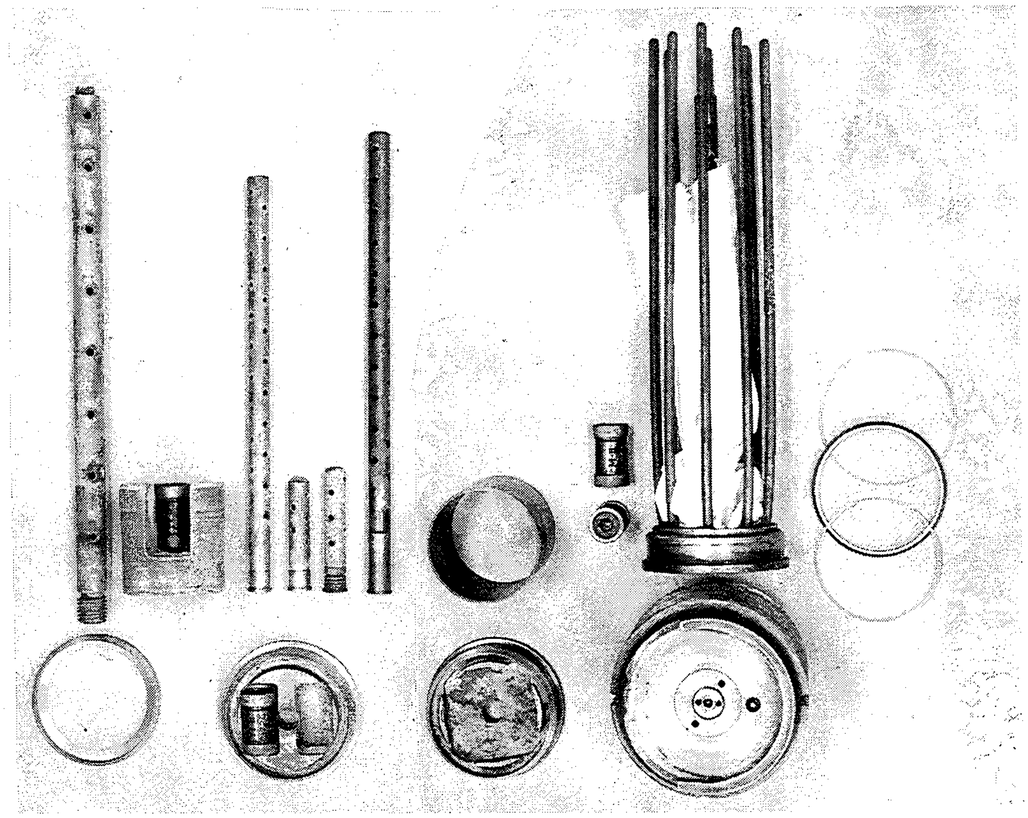


Figure 15. Evolution of breech-end components. See the discussion in the text. At the bottom left is the UDRI knife-edge seal with the ARL spit tube above it and the displacer to the spit tube's right. One of two M11 CC gages that straddle the spit tube is shown in position in the gage holder's slot. Below, next right, is the first ARL seal plate design with one of two M11 gages shown in the pocket. Above it are three service medium-caliber cannon primers. Left to right, they are the M28B2, the M38B2, and the MK22 L/70. A custom primer made using the M28's spit tube is next on the right. The third seal plate from the left is made so that the short phenolic tube above it can be hot-glued to lugs, forming a short cartridge in which bulk propellant is poured. The square recess accommodates the M11 gages. When the knife-edge seal on such a seal plate failed, the seal portion was machined away and a separate knife-edge seal as in the bottom left was used. At the bottom right is the ARL-designed plug breech with the Hexaseal breech plate with integral powder basket above it. A powder bag is shown in the basket, pulled down to reveal the tube of the custom primer. To its left are two M11 gages, and to the right the two O-rings and Hexaseal ring used for obturation. (A Hexaseal ring is just barely visible on the Hexaseal breech plate photographed.)

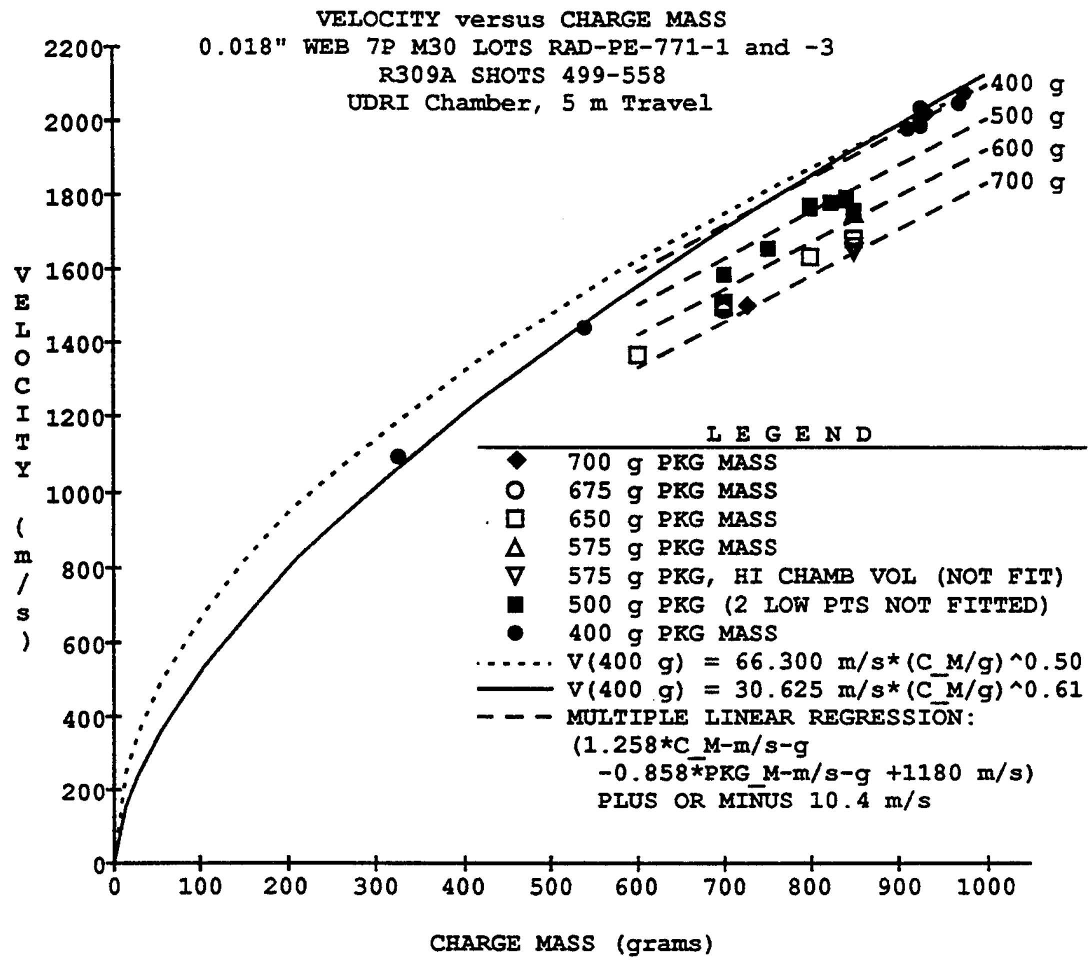


Figure 16. Empirical fits to applicable muzzle velocity vs. propelling charge mass data.

6. SETBACK FAILURES

With the discussion of the gun and its evolution in Section 5 as background, albeit necessarily quite detailed, the individual efforts to increase the velocity at which the massive threat rod could be successfully launched are now examined in separate sections.

At the beginning, we sought to minimize pusher mass. Unneeded pusher plate mass is unneeded in-bore mass, reducing maximum achievable velocity. Worse, unless specific measures are taken, the pusher plate strikes the target just behind the penetrator, potentially confounding the terminal ballistic results. However, with too little pusher plate mass, at some acceleration level the rod can set back through the pusher plate, just like a punch. Setback failure imposes the primary limitation on increasing launch velocity with a short rod of reasonable material strength.

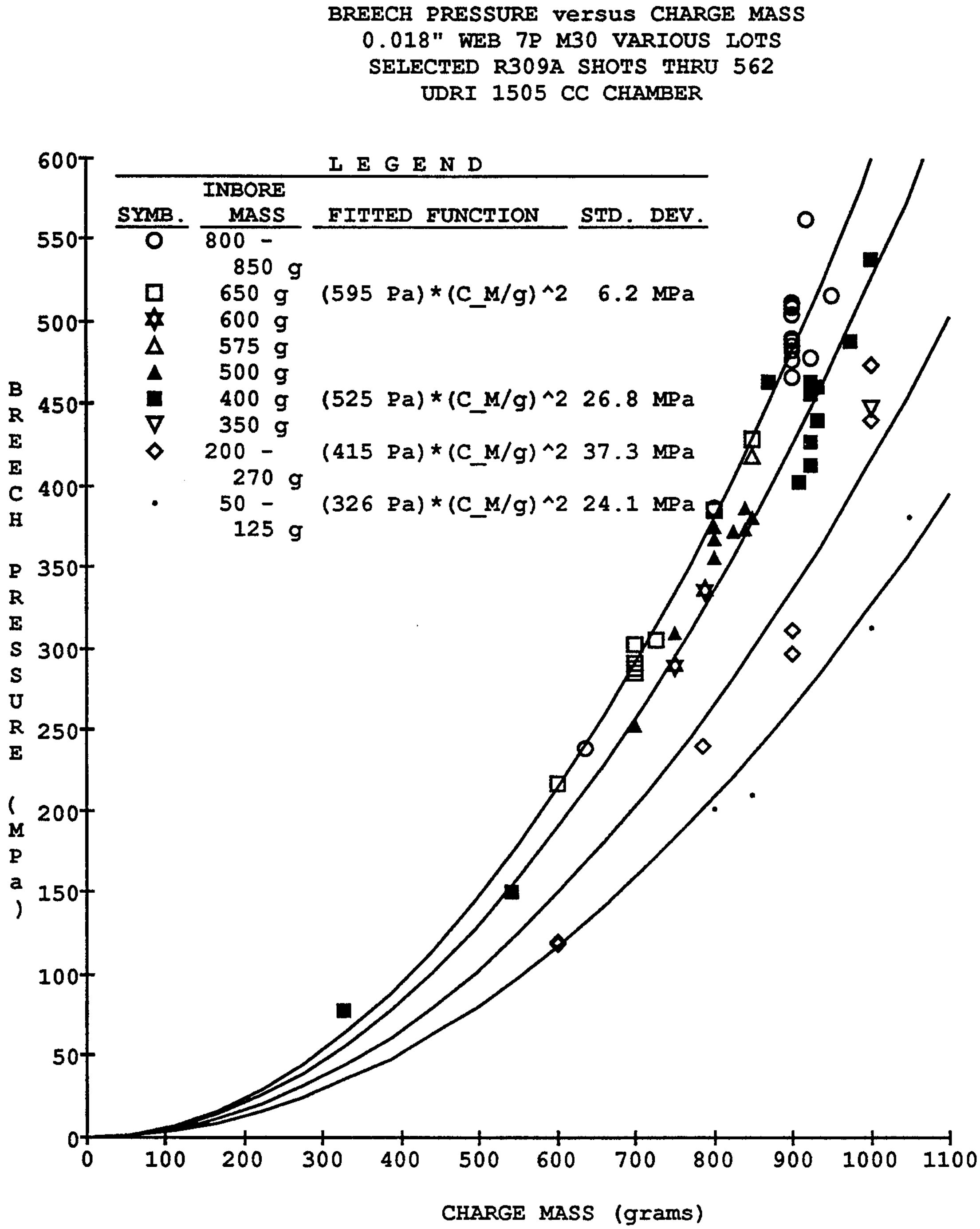


Figure 17. Empirical fits to applicable breech pressure vs. propelling charge mass data.

The first problem encountered in the high-mass program showed up as a cluster of setback failures. It is possible to induce setback failure in an otherwise properly designed launch package under acceptable

launch conditions by leaving a gap between the rod base and the pusher plate at shot start. We became concerned that when the interference between obturator and gun bore is such as to cause a stick-slip insertion, while at the same time the fit of the sabot on the rod is loose, it would be possible for the rod to slip forward in the sabot during ramming, leaving such a gap, perhaps leading to perforation of the pusher plate at an anomalously low charge mass.

As soon as a few setback failures were observed, two approaches to combat them were taken. Careful attention was paid to sabot OD vis-a-vis bore ID as it changed with bore wear, so that the sabot was made to begin to grip the rod tightly before the obturator began to enter the bore. Secondly, the amount of interference between the obturator and the bore was more carefully managed, so as to reduce the incidence of stick-slip fits. Because these steps were taken promptly, there was not enough data generated to be able to conclude whether or not the rod was actually sliding forward in the sabot and whether or not the changes in the sabot tolerancing resulted in any improvement in performance.

7. SERVICE M28 PRIMER EXPERIENCE

Our goal in switching to the service M28 primer had been to streamline operations and increase safety. To our surprise, use of the service M28 primer had to be discontinued for safety reasons after four shots, when the P-T traces suggested pressure waves indicative of base ignition of the propelling charge.

The interior ballistic data from these four shots were compared with that from the early high-mass shots using a hand-assembled priming train, as well as the data from the first two shots using the rather stubby M38 primers in the original powder bag. The data were carefully examined for trends. Those data felt to be the most important were then extracted, tabulated, and examined further. With the large number of changes of conditions, the plethora of parametric and nonparametric variables involved, and the limited number of shots, only major trends could be discerned with any degree of certainty.

Table 2, extracted from the interior ballistics database for R309A, lists the data I feel to be the most important to understanding M28 performance. The data are sorted by class of igniter tube or primer, then by ascending propelling charge mass. Most entries are self-explanatory.

In Column 2, the igniter tube model 81006-2 is the early heavy-walled custom long spit tube (Figure 11). Column 6 presents the average pressure measured by the two M11 CC gages at the breech

Table 2. M28 Study. Extracts From Interior Ballistics Log, R309A, Shots 151–175

R309A Shot. No.	Ign. Tube Mod.	Ign. Delay	Charge Mass (g)	In-bore Mass (g)	Avg. CC Press. (MPa)	Acc./k (Mm/s^2)	Pusher Plate	Results/ Comments	135 CC Dsplcr. Used	Launch Package Fit	Piezo-1 Pressure (MPa)	Piezo-1 Trace Shape	Muzzle Velocity (m/s)
160	81006-2	Prompt	637	799.32	239	0.60	0.2-in Ti		YES	Light Jacking	223	C	1330
162	81006-2	Prompt	800	799.15	387	0.97	0.3-in Ti		YES	Stick-Slip	365	I	1533
161	81006-2	Prompt	850	799.18	423	1.06	0.2-in Ti	Setback	YES	Stick-Slip	400	II	—
163	81006-2	Prompt	900	801.99	497	1.25	0.3-in Ti	Setback	YES	Moderate Jacking	466	II	—
164	81006-2	Prompt	900	801.29	508	1.27	Double		YES	Stick-Slip	468	C	1652
165	81006-2	Slight	950	852.20	516	1.21	Double		NO	Stick-Slip	485	C	1626
170	M28B2	Prompt	900	839.62	531	1.26	0.3-in 17-4PH		BR. PL.	Light Jacking	NR	NR	1562
172	M28B2	Prompt	919	849.80	562	1.32	0.3-in 17-4PH	Setback	BR. PL.	Moderate Jacking	494	IPPP	—
171	M28B2	Prompt	925	850.00	541	1.27	0.3-in 17-4PH	Setback	BR. PL.	Stick-Slip	486	IPPP	—
169	M28B2	Prompt	950	851.80	444	1.04	Double	Setback	BR. PL.	Stick-Slip	421	IPPP	—
173	M38B2	1.5 s	925	851.53	478	1.12	0.3-in 17-4PH		BR. PL.	Stick-Slip	452	IIPP	1594
174	M38B2	Prompt	925	849.51	531	1.25	0.3-in S7	PP Broke	BR. PL.	Light Jacking	490	IPPP	—

Priming: 81006-2: A magnum large rifle primer ignites 1 g of pistol powder in a 300 H&H magnum cartridge case, which ignites 20 g of Benite in a 300-mm-long spit tube.

M28B2: An M61 percussion cap ignites 20 g of Class 1 (coarse) black powder in a 240-mm-long spit tube.

M38B2: An M61 percussion cap ignites 3.56 g of Class 1 (coarse) black powder in a 54-mm-long spit tube.

MK22 L70: An M61 percussion cap ignites 3.75 g of Class 2 (fairly coarse) black powder in a 60-mm-long spit tube.

face, while Column 7 holds a figure for acceleration, as determined by multiplying the peak chamber pressure by the bore area and dividing by the in-bore mass times the (unknown) factor k relating breech pressure to shot-base pressure. Column 10 indicates whether the displacer was used to maintain constant chamber volume. "BR. PL." indicates that a breech seal or obturating plate was used to hold a medium-caliber primer and to seal the breech, as opposed to the earlier practice, where the long custom spit tube was screwed into the breech plug itself, and an independent knife-edge seal ring was used. Chamber volume is approximately the same with both approaches. Column 12 presents the peak piezoelectric gage pressure at the rear port, taken from the P-T plots. Column 13 is a nonparametric measure of the quality of the P-T trace, discussed earlier. "NR" indicates that no record was captured on that shot due to instrumentation failure.

The most obvious trend in this tabulation is that the more massive the pusher plate, the higher the powder loading it can withstand. The critical factor affecting this would be the in-bore acceleration, which is a function of the peak pressure and the in-bore mass. The in-bore mass varied little in this program and there is correspondingly little difference between the relative values for powder loading and peak in-bore acceleration. For convenience, I have used powder loading as the independent variable.

Plotting the data (Figure 18) reveals several other trends. Data for all shots with prompt ignition are plotted as solid symbols, while those for the two shots for which an ignition delay was noticed are open. The relatively lower pressure for these two is quite apparent. A fit to

$$P = A * C^2$$

(P is the pressure and C the charge mass) fits the data quite well. The solid line is the fit to all data without ignition delays, while the dotted lines are the upper and lower confidence limits to this fit at a 95% confidence level.

The biggest effect noted is the apparent large scatter of the M28 data (squares) compared to that of the long custom igniter tube, PN 81006-2 (circles). The only reason for this large difference is a single low-pressure outlier for the M28B2 shot with the highest powder loading. The standard deviation of the regression of the above form to the data set for all but the two ignition-delay shots is 42.08 MPa, while that for the same set with this one outlier removed drops to 19.68 MPa.

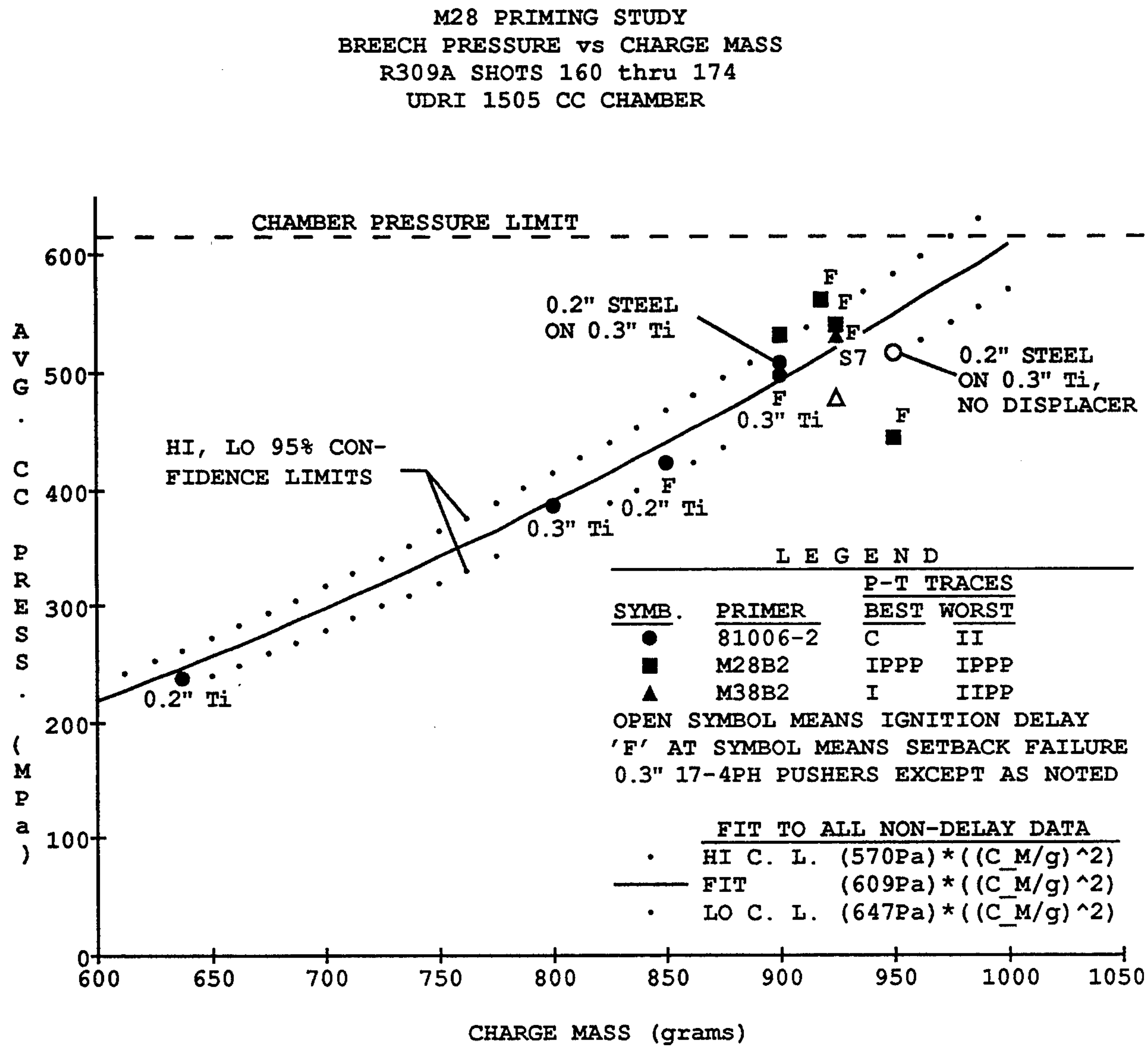


Figure 18. Breech pressure vs. propelling charge mass for custom, M28, and M38 primers.

Examination of the data suggests no particular single cause for the anomalously low pressure of the one M28 outlier. However, the severe downward trend of pressure with increasing powder loading in the three M28 shots in which setback failure occurred suggests that perhaps as powder loading climbs above the threshold at which the pusher plate fails, failure may come early enough in the ballistic cycle that gross venting of the propellant gases up the bore begins to significantly lower the peak pressure.

The maximum propelling charge mass that can be safely loaded into a gun depends on both the expected pressure (the fit to the charge mass vs. pressure data) and the variability in the data around the central trend (the standard deviation of the fit). The confidence limits reflect the region within which

pressures would be expected a preponderance of the time. Under the assumptions used here, a shot would be expected to have a pressure above the value of the upper confidence limit approximately 1 time in 20. In our case we have set the maximum allowed propelling charge at the value at which the upper confidence limit equals the pressure limit of the gun.

By discarding the lowest-pressure M28 datum, a more conservative estimate of the expected pressure should be obtained (i.e., higher pressures should be predicted). Thus, a lower value for the maximum permissible propelling charge should be generated. In this specific case, however, though not shown on the graph, the main result of discarding this datum is to raise only the lower confidence limit. The central trend rises slightly, but the upper confidence limits are identical in both cases. Thus, no actual change in operating limits would occur as a result. Where it can be arranged, as it can be with our access to custom production of propellant, the safest approach is to select a propellant granulation (web size) such that the required charge mass exceeds the chamber volume before the maximum allowable pressure can be reached. The upper confidence limit cuts the pressure limit for this gun just about at a 1,000-g C-M for this nominally 850-g in-bore mass projectile using undeterred 0.46-mm (0.018 in)-web, 7-perf. M30 propellant.

I consulted with Mr. Sassé (1991) of the Interior Ballistics Division (IBD) regarding the unexpected bad performance of the M28 primer. The experience that he and his associates had in trying to use the M28 primer to study the burning characteristics of black powder explained our results (Sassé et al. 1984). They used the M28 in its service configuration, in which the spit tube is essentially completely filled with a load of 20 g of Class 1 (coarse) black powder. Observing the propagation of burning up the packed granular bed of black powder, they noted that usually the flame front advanced smoothly. However, in some instances, flame would issue from the first spit holes and then a delay would occur before flame came from the rest, sometimes almost simultaneously. They also noted that the spit tube was blown off the primer stock occasionally.

This response suggested to them that on initiation of the base of the column of black powder, the grains would sometimes compact and then break up prior to or during ignition. Grain fracture leads to increased surface area and higher gas generation rates locally. This can lead to a runaway condition in which increased pressure fractures more grains, creating yet higher pressure, etc. The comminution of the grains also serves to block the flow channels, further localizing the disturbance and increasing its severity. Mr. Sassé characterized the M28 primer as "too brisant."

Comparison of the quality of the pressure traces, as characterized by the trace shapes listed in Column 13 of Table 2, clearly shows severe deterioration when we switched from the Benite-filled custom long igniter tube to the service M28B2 primer. Fearing that such ignition anomalies could result in severe pressure waves in the propelling charge and overpressure of the gun, use of the M28B2 primer was abandoned.

8. SERVICE M38 AND MK22 L/70 PRIMER EXPERIENCE

As discussed earlier, our new breech plug limited us to using service primers. The only primer on hand that could replace the M28 was the M38B2. It has, however, a much shorter spit tube, 54-mm (2.12 in) long. The full-length central sleeve in the propelling charge was suspected of bunching up, causing poor contact between the primer and the propellant bed, inducing the ignition delay experienced on the first M38 shot (173). For shot 175, the breech seal plate was redesigned as discussed earlier.

At the same time that we switched from the M28 to the M38 primer, we ordered delivery of the MK22 L/70 primer, which has the longest spit tube among primers we could find. It is only marginally longer than the M38 (64 mm [2.5 in] vs. 54 mm [2.12 in]) and has an additional pair of spit holes. The MK22 L/70 is a recent modification of the MK22 primer intended for use in ammunition for the U.S. 40-mm M266 variant of the Bofors L/70 gun, which was used on the canceled SGT YORK Division Air Defense Gun System. In the interim, the M38B2 was used with acceptable results in both the two-piece charge design and the unitary charge. Once received and used (in the unitary charge, shot 196), the MK22 primers gave similarly satisfactory performance for a long run of shots. In the M38 and MK22 shots, as typical on most other shots reported here, powder loadings varied in response to program needs, another factor contributing to variability. A careful researcher with similar problems would certainly stop and do a quick diagnostic program, but we were not permitted that luxury.

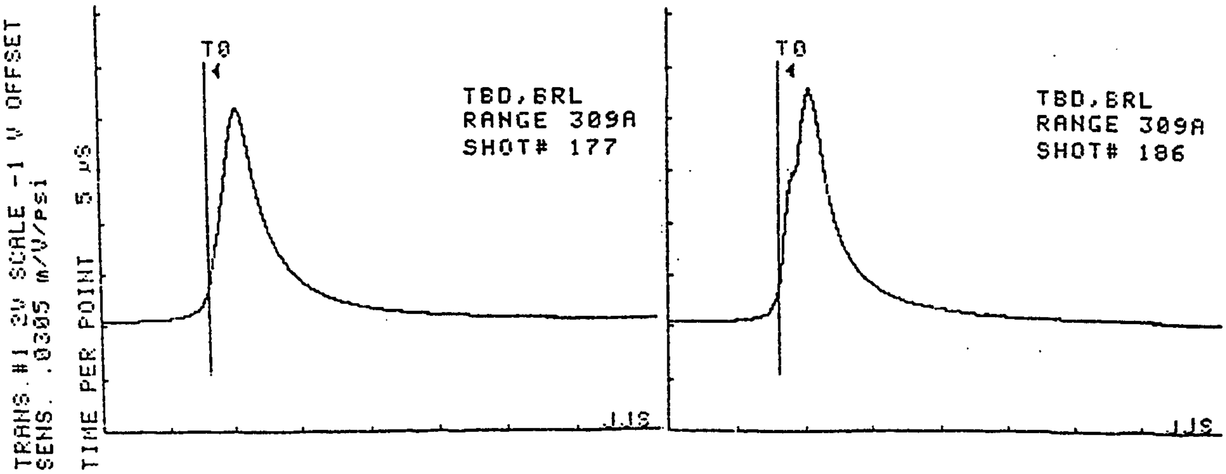
Changing to the unitary charge design seemed to eliminate the change in slope on the rising limb, and a number of P-T traces were clean of any sign of problems. However, with both the M38 and MK22 primers on low in-bore-mass, high charge-mass shots for other customers, with the unitary charge design and using 0.46-mm (0.018 in) web propellant, the tops of the traces on the rising side would frequently display a sudden flattening followed by a steep rise, though the peak pressure would remain about as expected.

Then P-T traces from two successive shots (259 and 260) exhibited a series of three smaller but sharper features ranging from inflections to peaks superimposed on the main curve, essentially indistinguishable from those seen with the service M28B2 primer on shots 169–172. Figure 19 presents the P-T traces. While we had been successfully launching the same high mass rod with the same propelling charge routinely, in one of these two shots, the launch package broke up in bore. No reason other than the priming could be found to explain the problem. The 500-MPa nominal pressure that we were expecting was not too far from the 615-MPa operating pressure limit of the gun, so we were concerned.

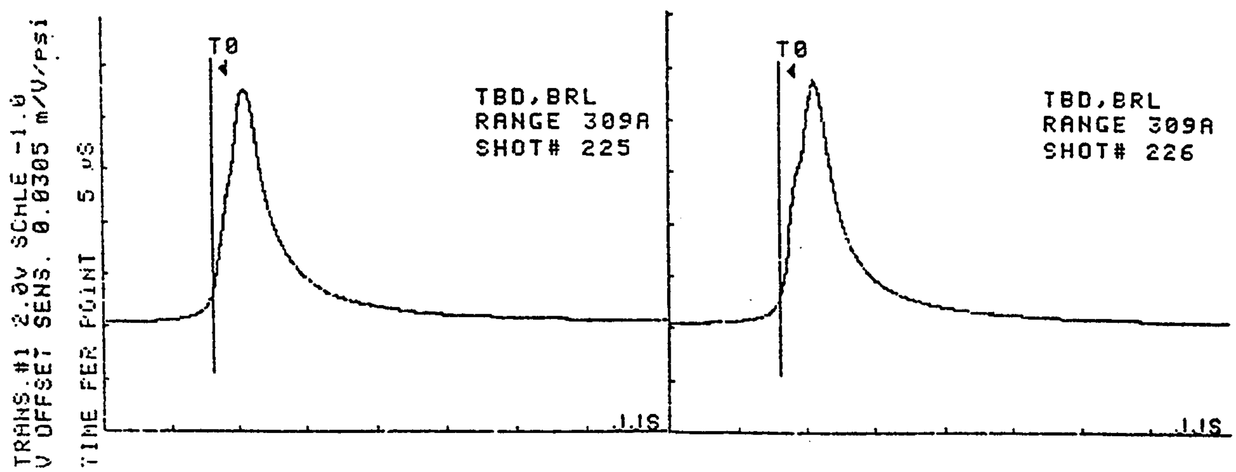
On reflection, with the exception of the elimination of the change in slope on the rising limb with the change to a unitary charge, the apparent small changes in performance between the three cases are probably artifacts of the sample sizes, and there is probably no actual difference in the average performances. The M38B2 and MK22 L/70 primers have considerably less black powder fill than the M28, so that mild priming problems are not reflected as strongly in the P-T curves. The primers are probably fairly well-behaved, but not ideal. It probably just took a lot of shots before several outliers in the population manifested themselves.

We consulted Fred Robbins (1991) of IBD, who observed that, as with the M28 primer, the P-T curves were strongly suggestive of pressure waves due to base ignition of the granular propelling charge. The M38B2 and MK22 L/70 primers are short enough relative to the main charge as it is. Perhaps the black powder fill of the M38B2 and the MK22 L/70 is also being overdriven and occasionally suffering grain fracture, resulting in grossly overstimulating the main propelling charge locally when it occurs. As explained by Mr. Robbins, there are two mechanisms recognized as inducing pressure waves. The more benign form is hydrodynamic waves, a resonance phenomenon in the chamber discussed earlier.

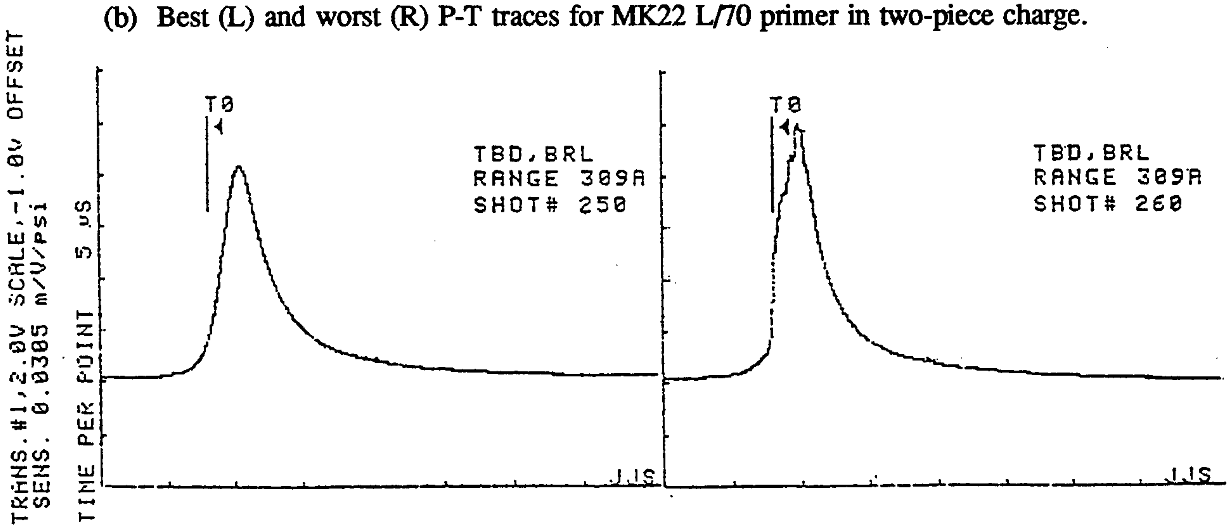
Higher pressure gradients, such as might initially arise from widespread grain fracture of the priming composition, can give rise to a more malignant form of pressure waves in the main propelling charge. This was alluded to earlier in the discussion of problems with the M28 primer. In areas of high pressure gradients in the propellant mass, drag forces between the flowing propellant gases and the propellant grains can cause high enough forces between grains in contact to cause fracture, resulting in increased surface area, resulting in higher gas generation rates, resulting in higher local pressures, and so on. Unlike black powder (Sassé et al. 1984), the burning rate of smokeless powder increases with increasing pressure. The combination of grain fracture and increased burning rate with pressure can result in a



(a) Best (L) and worst (R) P-T traces for M38B2 primer in two-piece charge.



(b) Best (L) and worst (R) P-T traces for MK22 L/70 primer in two-piece charge.



(c) Best (L) and worst (R) P-T traces for MK22 L/70 primer in unitary charge.

Figure 19. Possible influences of primer and propelling charge design. Best and worst P-T traces using the M38B2 and MK22 L/70 primer (short spit tube) are compared in a two-piece charge, and with those of the MK22 L/70 in a unitary charge. Traces are from 11 M38B2 shots and 27 MK22 L/70 shots in the two-piece charge, and 11 shots in the unitary charge cases.

dangerously high positive feedback situation in which runaway pressure can give rise to a breech blow. This can be exacerbated by a high base pressure and fractured propellant causing the column of granular propellant to block forward, increasing local pressures even more, making a breech blow a certainty.

Two solutions to the pressure wave problem were suggested by Mr. Robbins: either use a long igniter tube in conjunction with granular propellant, or switch to slotted stick propellant. Slotted stick propellant is made in the form of long circular cylindrical hollow strands of propellant with a full-length slot up the side of the strand to vent gases from the interior surface to prevent it from bursting as it burns.

It is hence inherently safer to use than granular propellant. The channels between the strands propellant facilitate flame penetration from a primer, providing less resistance to the gas flow pressurizing the propellant bed than the convoluted pathways in granular beds of propellant and making it inherently less sensitive to ignition problems. No slotted stick propellant appears to exist in the web size range necessary for the programs typical in R309A, and procurement of custom material would hence taken far too much time. Thus, we were forced to put aside the idea of using available military primers in favor of developing a custom primer design with a long spit tube.

9. CUSTOM PRIMING STUDY

9.1 <u>Benite Fill and a Booster Indicated</u>. In discussions with a number of knowledgeable people, all suggested the same approach: use the M28 hardware with Benite strands rather than black powder in the spit tube (Robbins 1991, Brandon 1991, Dibas 1991). Hill (1991) of the Army Armament Research, Development, and Engineering Center (ARDEC) at Dover, NJ, advised that they had actually pursued such a primer and that they had found that without a small amount of fine black powder in the primer stock to serve as a booster (which they retained with onionskin paper), there was a slight delay in propagation of pressure from the base spit holes to the tip spit holes.

Several igniter tubes from spent M28 primers were removed and cleaned. They are 11.5-mm (0.45 in) ID × 250-mm (9.75 in) overall length, with 44 flash holes 3.57 mm (9.64 in) in diameter. A single wrap of tracing vellum was dropped in. They were given various fills of Benite broken to almost the full length of the spit tube to roughly characterize benchmarks in loading densities. See Table 3.

Table 3. Loading of the M28's Igniter Tube With Full-Length Benite Strands

No. of Strands	Characterization of Loading Condition	Mass of Benite (g)
18	Fully Packed	21
14	About 50% Open Area	16
13	Slightly Snug	15
12	Easy to Dump Out	13.5
9	Tumble When Tube Is Rolled	10

Most entries are self-explanatory. With 14 strands of Benite, approximately 50% of the cross-sectional area of the igniter tube is occupied by energetic material, which is held in place quite snugly. With 13 strands, the fit is only slightly snug, though the spit tube needs to be shaken axially to get the strands out. With 12 strands, they fall out under gravity without shaking, the "Easy to Dump Out" case.

Four custom-loaded and unstaked M28 primers left over from an earlier unrelated ignition study were provided us by PFD. They were disassembled and reassembled with the cavity in the forward part of the stock filled to the top with 0.045 g of Class 5 (fine) black powder, retained by a disc of masking tape.

The spit tubes were loaded with 14 g of Benite strands. One of the spit tubes had thin brass shim stock blocking all of the spit holes. One had thin brass shim stock blocking only the rear half of the holes. The other two had paper covering all of the spit holes. We decided to use them as is on typical high in-bore-mass shots and note their performance.

P-T traces were captured on three of these four shots. The traces were clean of any alarming features. A slight ignition delay was observed on one of the shots with paper covering the spit holes.

9.2 Custom Primer Stocks Designed. Lacking equipment to safely disassemble the staked spit tube from the stock of the loaded service M28 primers, custom medium-caliber primer stocks were designed to simulate an M28-like primer stock to continue the studies. The breech seal plate is about 20 mm thick, and a pair of CC gages potentially interfere with fire distribution into the charge at the spit tube's rear, so the stocks were made with an overall length of 50 mm to provide deeper penetration of the first spit holes into the propelling charge. A pocket for a booster charge of propellant in the forward end of the

stock was made with a pair of drills such that chaff from a smaller- and a larger-diameter paper punch could be used to close the bottom and top of the cavity. The base end accepts an M36A2 percussion cap used for 20-mm and 30-mm ammunition. The stock is threaded to take the spit tube from an M28B2 primer. The OD and rim are made to the dimensions of a standard primer stock. This creates a heavy interference fit with a service cartridge case, so the breech seal plate primer pocket was intentionally made oversize so that a service primer can be inserted by hand. The initial design drawing for this primer stock is A-SILSBY-91002 (PN 91002).

Fourteen spit tubes were salvaged from fired M28B2s. The spit tube threads of service primers are deformed by staking, so the shop made an expandable custom tap to 0.49-32 UNS as used on service stocks, and restored the threads.

Figure 20 shows a typical (though in this case less effective) configuration of the primer system in which percussion cap, booster, and Benite strands are isolated from each other by paper seals.

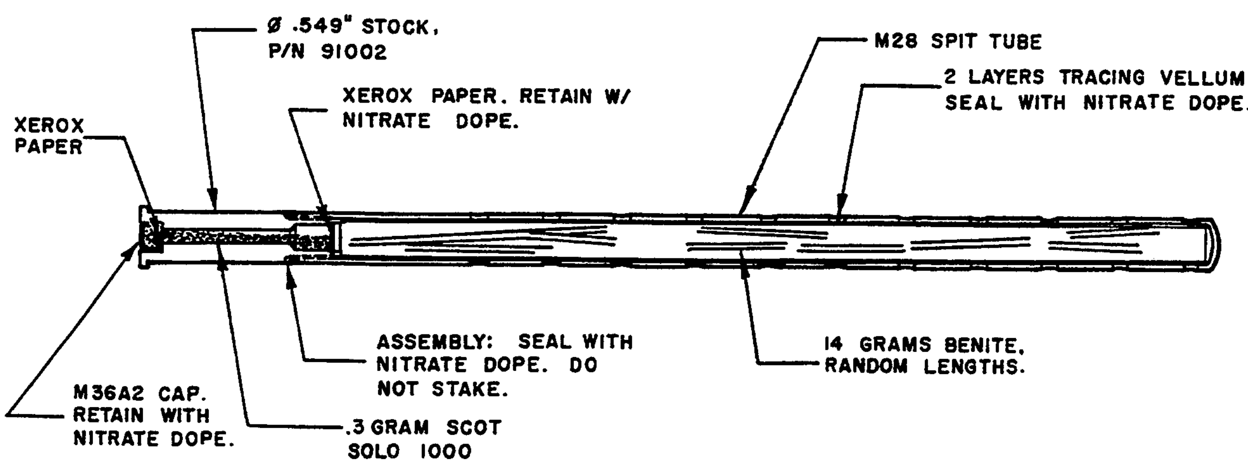


Figure 20. Typical primer configuration tried in the priming study. The configuration shown is not the optimum design.

The striker tip on the firing pin was machined to conform to the geometry of the test firing fixture for the M36 percussion caps (0.8 mm to 1.0 mm [0.030 in to 0.040 in] on radius) on the advice of Mike Cook (1991) of the Lake City Army Ammunition Plant.

At this point, the high-mass package had been standardized at 900-g in-bore mass. For the first test of the candidate primer recipe, a minimal propelling charge was used. An ignition delay would indicate inadequate priming. For the first shot (267), the primer stock was primed with only an M36A2 percussion cap (no booster powder), with a single layer of copier (xerography) paper over the end of the forward pocket, to keep the Benite out of the primer pocket. No cement was used to hold the paper in place. The spit tube contained 14 grams (12 strands) of Benite, with no paper over the spit holes. The main propelling charge was 600 g of 0.64-mm (0.025 in) equivalent web M30, a blend of 71% by mass 0.46-mm (0.018 in) web, and 29% by mass 1.07-mm (0.042 in)-web, 7-perf. cylinder granular propellants. The bagged charge was centralized on the igniter tube by twisting the powder bag and counterwrapping it with a single spiral of masking tape. An ignition delay of about 1 s was observed, but the pressure traces were clean. The chamber pressure as measured by the average of the two CC gages was about as extrapolated from other data, 193 MPa (28 ksi).

Shot 268 duplicated shot 267 in all ways except that the forward pocket in the primer stock was filled with Scot Solo 1000 pistol powder in lieu of black powder, weighing approximately 0.3 g. Again, the forward pocket was closed with copier paper, and no paper was used to cover the spit holes. Two new pressure transducers were installed in the chamber. Prompt ignition and clean traces were observed. The average of the two CC gage pressures was 187 MPa (27.1 ksi).

For shot 269 and following, having expended the lot of larger web-size propellant we had been using to date, the 0.65-mm equivalent web was achieved by blending 50% by mass 0.46 mm (0.018 in) and 50% by mass 0.80-mm (0.0317 in)-web, 7-perf. cylinder granular M30 propellants. The propelling charge mass was raised to 850 g. Prompt ignition and clean traces were observed. Average CC pressure was 308 MPa (45 ksi).

For shot 270, using the standard 900-g package, the charge mass was raised to 986 g of 0.025-in equivalent web 7-perf. M30, which routinely delivered the desired 1,600 m/s when the M38 and MK22 primers were used. Ignition remained prompt and the traces remained clean. However, velocity was measured at 1,651 m/s. When smooth, the P-T traces should have a lower peak and be wider than bad traces under otherwise similar loading conditions (have a higher piezometric efficiency), resulting in higher launch velocity. (Additional shots under conditions duplicating those leading to this unexpected increase in velocity were fired well-after the high-mass program was finished, and this improvement in performance is real.)

Using the same primer recipe, seven additional shots were fired for an unrelated program using an 800-g package mass. The same propellant blend was used and the propelling charge was varied from 850 g to 976 g to achieve the requested velocity range. Ignition was prompt and all pressure traces were clean.

9.3 <u>Attempt to Achieve Common Primer Recipe With the 40-mm Lab Gun</u>. The 50-mm gun was then taken out of service following shot 276 to permit a small-arms program to be fired in R309A. We then began shakedown work on a laboratory gun based on the Bofors 40-mm L/70 air defense gun. The U.S. version of its cartridge case holds up to 500 g of propellant and takes the U.S. family of medium-caliber press-in percussion primers. It is as long as the chamber on the 50-mm gun, 350 mm (14 in) but averages about 55-mm (2.1 in) ID as opposed to the 50-mm gun's 75-mm (3 in) chamber ID.

An attempt was made to standardize the primer design for use in both the 50-mm and the 40-mm lab guns. The original custom primer stocks, made of brass, had by this time swelled to the point of near uselessness from the internal pressure. They were replaced by a second set of custom reloadable stocks of slightly different design. They were made of precipitation-hardened 17-4PH steel at HRC 44 for higher strength. The ID of the powder pocket was reduced slightly to increase the wall thickness. The OD was decreased so that the new stock would fit into the service case without application of force, and the percussion cap pocket was enlarged just slightly to permit the cap to be inserted likewise. Nitrate-based model airplane dope was used to secure the primer stock in the cartridge case and the percussion cap in the primer stock.

The loading of 14 g of Benite, up to now standard for the 50-mm gun, apparently overdrives the propelling charge for the 40-mm gun, producing mild pressure fluctuations. A new lot of Benite was obtained, which had been broken to 175 mm (7 in) and so could not be made to fill the entire length of the spit tube as before. Using the same primer loading geometry as before, we decreased the Benite fill. The primer stock and booster failed to ignite a fill of 7 g of 175-mm-long Benite, shattering the strands and driving them to the end of the tube. Increasing the Benite charge to 10 g of 175-mm-long strands worked well in the 40-mm gun.

We were requested to supply the 40-mm gun to a customer for remote use. Feeling confident that the loading was correct, a lot of about 20 primers were loaded with 10 g of Benite broken to 175-mm lengths. Anticipating delay between assembly and use and exposure to humid conditions, the spit tubes were lined

with two wraps of tracing vellum sealed with nitrate dope and thoroughly dried. A disk of copier paper was cemented into the bottom of the percussion cap well with nitrate dope and thoroughly dried. The powder pocket was loaded with about 0.3 g of Scot Solo 1000 (about half full), retained with a copier paper disk retained by and overcoated with a layer of dope. The loaded spit tube was screwed home and the joint overcoated with dope. This is the configuration shown earlier in Figure 18.

The firing system in which the 40-mm gun system was used incorporated an automatic sequencer, so that short ignition delays would not be apparent. A 0.2-s delay in ignition was observed on the first shot. No delays were apparent on about a dozen others. Tentatively, the design seemed to work acceptably in the 40-mm gun system.

9.4 Paper Barrier Causes Ignition Delay. Pursuing the goal of commonality between the 40-mm and 50-mm systems, the residue from this lot of primers was then tried in the 50-mm gun. They appeared to be inadequate, exhibiting a consistent ignition delay of about 0.5 s, but very smooth P-T traces. There was also a significant increase in the variability of the velocity, probably due to the shot beginning to travel before the propellant began to burn in earnest.

Lightly wadding the forward end of the spit tube with toilet paper to place the end of the 175-mm-long Benite strands close to the end of the stock did not eliminate the ignition delay. Ten grams of Benite broken to the full length of 220 mm (8.7 in) worked worse in the 50-mm gun. In one shot of three, the Benite did not ignite. Several of the strands were shattered, and the paper covering the spit holes was blown open on only the first three. On the ignition failure shot, the spent stock was unscrewed, 0.1 g of Scot Solo 1000 powder was sprinkled into the end of the Benite, and a new stock (with its 0.3-g Scot Solo booster charge) screwed on. The shot was refired successfully. In all three cases, there were 0.5-s ignition delays, and the P-T traces showed pressure waves.

We were puzzled when the ignition delays persisted when we shifted back to a 14-g Benite loading. We suspected that perhaps the Benite or booster propellant had picked up moisture with age. We tried fresh powder. We experimented with the length of the Benite strands. We tried a spit tube without the paper liner.

How true the saying: "This problem, once solved, is simple!" The culprit turned out to be the paper seal in the cap well. Discussions with Kevin White of ARL's PFD (1992) provided a plausible

explanation. The volume in the cap well is apparently enough to drop the pressure on the NC-based powder in the communicating drill hole below that required to reliably ignite it. However, a small amount of propellant in the cap well raises the pressure enough to assure good ignition.

Trying again in the 50-mm gun to find a primer loading that would also work in the 40-mm gun, we tried a 10-g Benite fill without the paper in the cap well, and experienced an estimated 0.25-s delay. Boosting the priming to 12 g of Benite reduced the incidence of slight delays to once in three shots, still not good enough. It looks as if a primer recipe unique to the 50-mm gun will be required to reliably obtain maximum launch velocity for the high-mass threat projectile discussed here. However, it is possible that using black powder as the booster might permit commonality.

9.5 Mechanical Design Changes Needed in Firing Train. A drawback to the primer system as illustrated earlier in Figure 20 is that a disc from the base of the percussion cap is often sheared out and driven over the firing pin into the firing pin hole. This is a minor annoyance in the 50-mm gun, in which the plug breech screws in. The biggest problem is fouling of the firing pin assembly with powder gases, requiring frequent disassembly and cleaning. It is a major problem in the 40-mm system, with its drop-block action. The operating handle must be repeatedly forced up and down in an attempt to drive the brass sub-flush, or the breechblock beat open, shearing off the intruding brass. We experienced the same problems with Bofors service ammunition, implicating my firing pin design. A potential cure is discussed in Section 12.

10. SABOT EVOLUTION

The design of the sabot evolved concurrently with the improvements to the interior ballistics of the gun. The sabot used for most of the program is depicted in Figure 1. Initially, the sabot contacted the rod periphery along only 80% of its length. The sabot was machined as four accurately mating independent petals. The pusher plate was recessed into the base of the sabot, and the obturator length adjusted to bring the mass to a desired value. The incidence of high yaw shots seemed excessive, so the sabot was lengthened.

High yaw continued. The images of the pusher plate and obturator at the striking flash x-ray stations were more puzzling than helpful. Occasional small notches were observed in the periphery of the pusher plate, and the obturator was frequently seen flying highly yawed with its front end smeared. The sabot

had already been stripped, so these results were attributed to interaction with jetted sabot material at the stripper plate, and with the stripper plate aperture itself.

Mr. Edmanson designed and installed blast-resistant cassettes and two orthogonal channels of 150-kV flash x-rays for muzzle diagnostics. The occasional cuts observed in the periphery of the pusher plates were observed at muzzle exit, as was the smeared obturator face, so the problem originated in-bore. The gas leakage past the obturator was frequently pushing one or more of the sabot petals forward on the rod, leaving an unsupported region near the base of the rod. I changed to a traditional interlocking-petal sabot, which reduced, but did not eliminate, the incidence of high yaw shots.

Gas leakage past the obturator continued to be the root cause, pushing the entire sabot assembly forward on the rod from time to time, usually accompanied by unacceptable yaw. I lengthened the obturator to increase resistance to gas leakage to no avail. Finally, for shot 250, to reduce the pressure between the sabot and pusher, I vented the sabot-obturator interface forward into the gun bore. To achieve this, a slot was cut radially inward in the sabot base from its periphery, communicating with 5- to 7-mm-diameter holes drilled through the length of each sabot petal, just tangent to the edge of the 1.6-in-diameter (40.64 mm) pusher plate seat in the base of the sabot. See Figure 21.

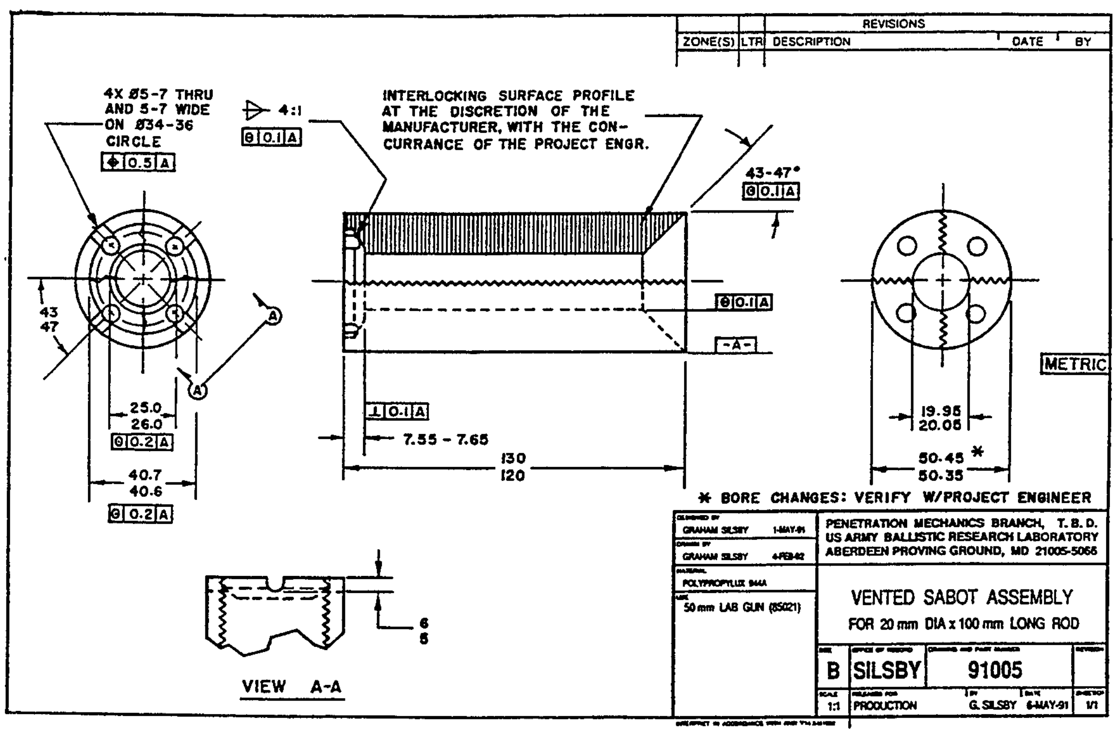


Figure 21. Vented, interlocking-petal sabot design for the 20-mm-diameter × 100-mm-long 555-g threat rod.

Muzzle x-rays provided the answer to the puzzling pusher plate pictures. With the vented sabot, the pusher plates were almost always notched in four places at shot ejection, and the obturator face eroded, initially in a cruciform pattern. With the venting, the flow of the high pressure hot gases past the pusher's edge literally melts and blows it away. However, the yaw problem almost disappeared.

The vented, interlocking-petal launch package design is highly successful. It has eliminated the high yaw that to date has accompanied the failure of obturation as bore wear becomes terminal. This design has since been adopted as the standard for all laboratory discarding-sabot launch packages fired by us from both the 40-mm and 50-mm guns to date. The package for launching the 555-g L/D 5 armor threat rod weighs 900 g, a ratio of payload to package mass that compares favorably with that of weaponized traction sabots.

11. SUMMARY AND CONCLUSIONS

We exceeded the desired 1,600-m/s striking velocity out of the UDRI 50-mm, high-pressure powder gun for the 555-g L/D 5 short rod used in this program. An evolutionary approach was taken to settle on the ignition train and propelling charge geometry. Likewise, incremental launch package design improvements resulted from observation and experience. Each separate improvement discussed here was more or less of the same importance as the others, and without them all, we would not have reached our goal.

11.1 <u>Ignition and Propulsion System</u>. The ignition system developed is one with a long spit tube with a relatively light fill. Benite strands are used instead of granular black powder to promote unimpeded flame spread. Careful tailoring of the booster charge is needed to provide prompt pressurization and ignition of the Benite without creating excessive internal pressure in the primer. Central ignition of the small-granulation M30 propellant eliminates pressure waves when the ignition package is proper.

Based on very limited experience, the final priming train design has yielded higher velocities for the same propelling charge mass when compared with results using primers with short spit tubes. This is attributed to the increased area under the P-T trace, which is broader and frequently is of lower peak pressure. Shot-to-shot variation in the peak pressure is also reduced with central ignition. This permits loading a slightly higher propelling charge mass, yielding slightly higher velocities while still staying within the bounds of safe practice.

The poor performance of the M28 primer is taken to be due to sporadic blockage of the gas-path up the powder column. When this happens, flame initially issues only from the first few spit holes. In such instances, the M28B2 over-vigorously base-ignites the main propelling charge, an undesirable and even dangerous circumstance. The M38B2 and MK22 L/70 probably act likewise. With less priming powder in those two igniters, the effect on the main propelling charge is probably not so great.

Culminating a series of improvements, Mr. Edmanson's innovative and simple powder bag design (hot gluing a cardboard disc incorporating a primer hole to the base of an otherwise straightforward powder bag) assures intimate contact between igniter tube and propellant. It provides a sure seal for propellant around the full-length primer intruding into the propelling charge. We were even able to extract the primer from a complete propelling charge and replace it without opening the powder bag in one instance. And this design simplifies loading the propelling charge.

Without the use of custom-manufactured propellant to achieve the optimum web size, I believe it would have been impossible to achieve the desired velocities. After conclusion of the effort, we have begun using computer codes to model the performance, which may allow us to settle this question.

An effective web size of the undeterred multiperforation M30 propellant of 0.64 mm (0.025 in) was indicated and was obtained using available 0.46-mm (0.018 in) custom-manufactured propellant and an available experimental military 0.81-mm (0.0317 in) web powder. The large web size reduces peak pressures and allows marginally higher propelling-charge masses, and hence permits achievement of higher velocities. It also provides an inherently safer mode of operation because it is impossible to even approach the maximum pressure limit on the gun with even the heaviest package used to date.

The most impressive lesson learned during this effort is the exquisite sensitivity of performance to seemingly minor changes in the priming and propelling charge design.

11.2 Bore Wear. Even using M30 propellant to minimize erosivity, the extreme conditions usually imposed in terminal ballistic launchers result in rapid erosion and heat-checking of the barrels. In the case of the UDRI 50-mm barrel, made of the usual 4340 steel heat-treated to HRC 32–36, it should have been re-bored after about 200 shots. Money was simply unavailable to do this. The bore condition at that point was so deteriorated as to be unacceptable.

With no replacement barrel available, we reconditioned the gun by cutting off the first meter of the barrel. The improvement in obturation has just about exactly offset the loss in performance due to the reduction in shot travel, so that we are using the same powder loading curves as before.

A replacement barrel of similar steel was acquired from Watervliet Arsenal to permit uninterrupted service when the barrel needs to be sent out for rework. For continuity of operations, several extra wear sections have been acquired as well. The UDRI design was rationalized so that all barrel connections are the same, using all right-handed threads. Later experience showed the UDRI left-hand, right-hand design to be superior, as the barrel sections do not have to be rotated in their mounts to join them. The barrel OD was increased to a nominal 6.25-in OD to allow enough material to account for drift of the bore axis relative to the OD so that full threads can still be machined if the barrel is cut anywhere along its length. The first meter (40 in) of the barrel is made as a separate wear section.

To give a rough idea of the wear conditions, we have put 140 shots on the Watervliet barrel and the breech end has grown from a uniform cylinder of 50.39-mm (1.984 in) ID to 50.62 mm (1.993 in) ID at 50 mm in from the RFT and 50.65 mm (1.994 in) at 200 mm from RFT after 100 shots, and 50.72 mm (1.997 in) and 50.80 mm (2.000 in) respectively after 140 shots. The loading conditions approximate those earlier on the UDRI barrel, with the exception that no wear-reducing additives have been used and all shots are with M30 propellant.

The current barrel was at the same state at the UDRI barrel when yaw problems began to surface, as discussed in Section 5.4.3. The heat checking has progressed to the point where axial gas wash channels are establishing themselves and eating below and obscuring the circumferential thermal fatigue cracks. I estimate that the barrel will again become unusable due to obturation failure at 200 shots, as was the case of the UDRI barrel.

11.3 Launcher Hardware. The powder basket with its Hexaseal ring and PTFE seals has been a very reliable design, consistently providing leak-free service when locked up forcibly. Good judgment and a good right arm are needed. Still, any foreign matter in the seal area will precipitate a leak, requiring remachining the chamber seal surfaces, an expensive proposition.

Replacement of the powder basket with a custom-designed stub case of 17-4PH steel precipitation hardened to HRC 44 has improved on this. This design has a case-wall mimicking that of the U.S. 57-mm brass case. Ordnance tape is used to form a simple initial seal at the case mouth before loading each shot.

A close-fitting 17-4PH ring is used to fill the annular zone in the chamber machined away over the years in successive seal surface redressing operations. The use of the stub case has recouped about 50 g of powder capacity, with concomitant increase of possible velocity.

One other item of experience regarding the barrel is notable. The original left hand-right hand threaded connection is superior to the rationalized right hand-right hand connection, as it allows the barrel sections to be aligned to each other, then drawn together by the sleeve without disturbing the alignment.

11.4 Development of the Vented, Interlocking-Petal Sabot. Though given short treatment in this report relative to the priming study, the development of the vented sabot is the most significant contributor to the success of this effort. It has overcome a very serious and longstanding limit on performance of push-launch packages from badly worn laboratory guns.

Gas blowby frequently would push one or more of the sabot petals forward on the rods, resulting in unacceptable yaw when using the traditional launch package design. Venting the obturator blowby up the barrel, when coupled with traditional interlocking petals, has greatly reduced the incidence of bad shots and allowed us to extend the barrel life to 300 shots before a rebore was unavoidable. This sabot design has become a standard in R309A.

12. RECOMMENDATIONS

A custom lot of nominally 0.64-mm (0.025 in) web M30 propellant was recently received, though with an actual average web size of 0.56 mm (0.022 in). This is probably large enough to obviate the need to blend propellants except for a very few shots. The Aberdeen Test Center (formerly the U.S. Army Test and Evaluation Command's Combat Systems Test Activity [CSTA]) has funded a first iteration in custom-production of 0.38-mm (0.015 in)-web, 7-perf. M30. The die design used by the producer, the U.S. Army Radford Army Ammunition Plant, yielded a good geometry of the finished product.

The die geometries for the suite of custom M30 granular propellants needed to span the range of applications in the 50-mm and 40-mm guns have been experimentally determined over the past 10 yr. Preliminary inquiries into procuring slotted stick propellant are being made, in the hopes that enough funding will become available for management to risk commitment to the first iteration of slotted-stick die design, a step up in operational efficiency and safety.

To eliminate fouling of the firing pin by extruded metal, we have switched to an improved primer stock design incorporating a firing plug behind the percussion cap. This design copies the successful design of service medium-caliber primers. The firing plug and its retaining ring, called a battery cup in service drawings, are salvaged from spent service primers used in a sister range.

A change to a more compact firing solenoid necessitated changing to a more sensitive percussion cap, a CCI 250-magnum large-rifle primer. It has a less-energetic output than the M36 cap we used in the work reported here and the M61 percussion cap in the service primers. The mounting means for the more compact solenoid still permits use of the larger solenoid firing box that is more or less a TED standard, if needed. The reduced cap output was overcome by using a larger quantity of booster propellant in the primer stock. Figure 22 shows the current custom primer stock design. The dimensions and tolerances are such that only slight force is needed to seat the percussion cap, and essentially no force is required to seat the firing plug and battery cup assembly. Experience indicates that the booster charge is just sufficient for acceptable reliability. However, the smaller percussion cap is blown out into the void around the striker, venting gas and fouling the firing pin again. It is suggested that the firing pin mechanism be redesigned as shown in Figure 23.

This suggested design has a number of important features. It is interchangeable and interoperable with existing firing pin assemblies. The body fits loosely in the custom breech block, with alignment provided and axial force borne by the close-fitting socket. The broad face is featureless, the assembly being screwed in and out with a key in the recessed end, which also protects against inadvertent depression of the pin. It is well vented, to reduce the forces the powder gases exert on the firing pin, driving it to the rear. A positive stop to the rear prevents the firing pin from going sub-flush with the breech face. This feature, coupled with a broad, slight outward curvature of the face, should ensure smooth travel in a drop-block action. The small sub-flush volume reduces the extrusion of the primer brass into the firing pin hole, extrusion which would tend to prevent a drop-block action from opening after a high-pressure shot.

The suggested firing pin is symmetric, so that no attention need be paid to how it is assembled into the firing pin assembly. If a firing pin were desired with a smaller, rounded tip for direct strike of a percussion cap, as with the Swedish 40-mm ammunition, however, care would have to be exercised to assemble it in the right orientation, and a mating, smaller hole in the housing would undoubtedly be needed to assure that primer material did not find its way into the firing pin assembly, jamming a drop-block action.

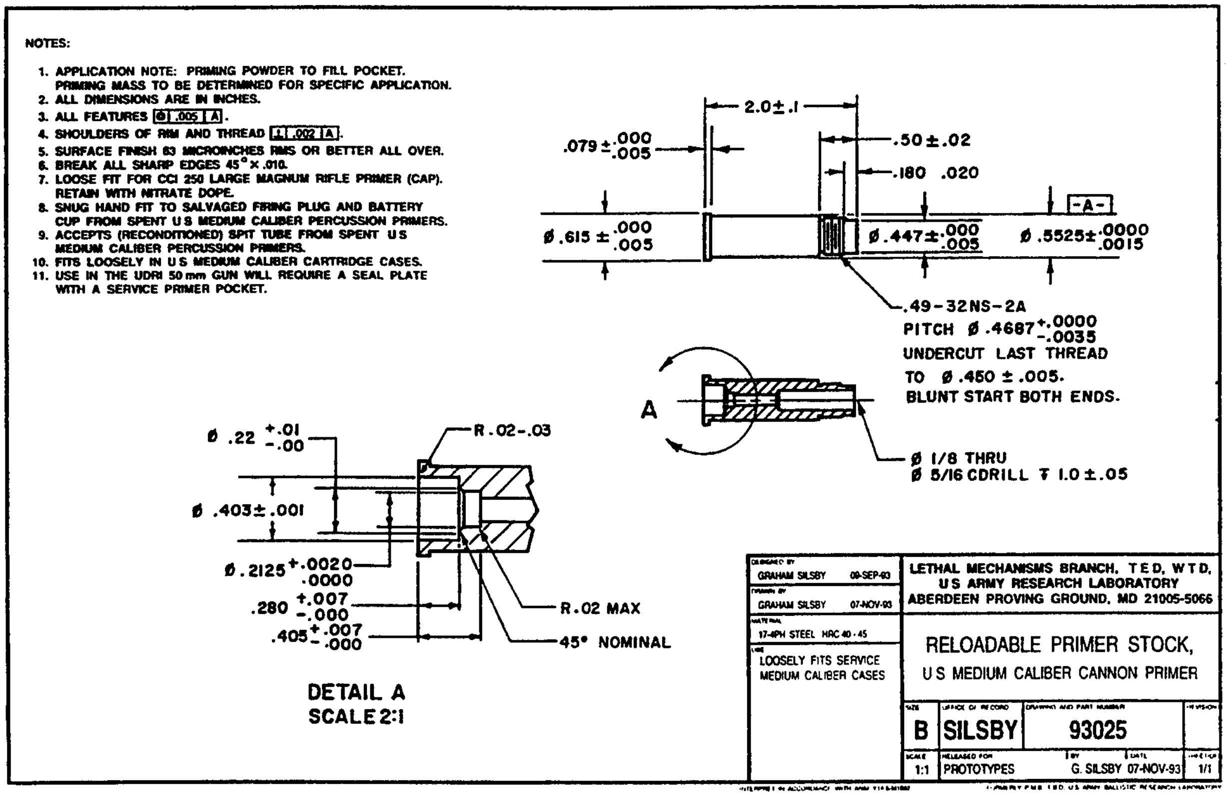


Figure 22. Custom primer stock accepting service firing plug. This is the current design, and is similar to an M28 primer with a reduced charge of Benite substituted for the black powder. A magnum large-rifle primer replaces the M61 percussion cap to permit use of a smaller firing solenoid mounted on the breech plug, for convenience in loading. When used in the 50-mm gun, the igniter tube is filled with 12 g of Benite.

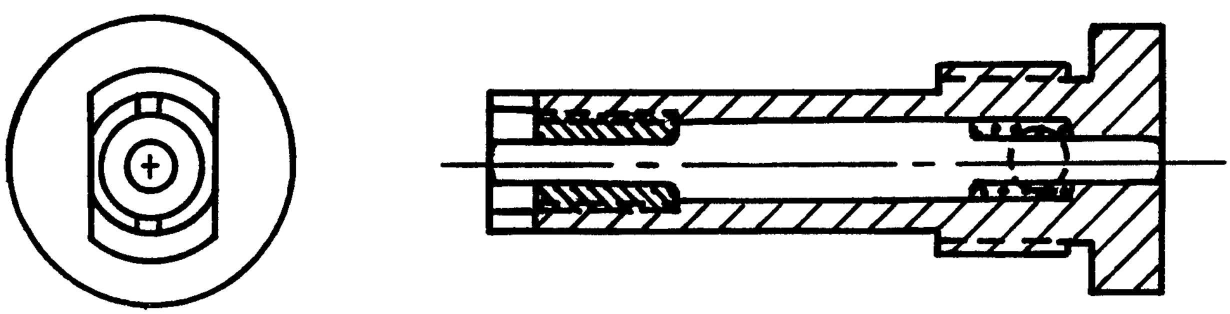


Figure 23. Suggested improved firing pin assembly.

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13. REFERENCES

Brandon, F. J. Private communication. U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, March 1991.

Burns, B. Private communication. U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, June 1981.

Clay, W., L. Burke, Jr., W. G. Thompson, and J. Harmon. "Time Zero Triggering System." BRL-TR-3319, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, March 1992.

Cook, M. Private communication. Engineering Services, Lake City Army Ammunition Plant, MO, 1 April 1991.

Deas, R. Private communication. U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD. Conversations with Louis Giglio-Tos of the U.S. Army Ballistic Research Laboratory, April 1981 and subsequently.

Dibas, M. Private communication. Day and Zimmerman, Inc., Lone Star Division, Texarkana, TX. Telephone conversations with author, March–June 1991.

Enderlein, M. W. "Armor Backpack Effectiveness Against Rod Penetrators at Ordnance Velocities." BRL-MR-3939, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, October 1991.

Federoff, B., and O. E. Sheffield, Ed., assisted by E. F. Reese and G. D. Clift. "Black Powder Modifications." Encyclopedia of Explosives and Related Items. PATR 2700, vol. 2, p. B 173, U.S. Army Picatinny Arsenal, Dover, NJ, 1962.

Geene, R. Private communication. "Interior Ballistic Simulations for the TBD 50-mm Smoothbore Gun." Memorandum, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, 4 August 1980.

Geene, R. Private communication. U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD. Conversations with Louis Giglio-Tos of the U.S. Army Ballistic Research Laboratory, April 1981 and subsequently.

Hill, R. J. Private communication. U.S. Army Armament Research, Development, and Engineering Center, Dover, NJ. Telephone conversation with the author, June 1991.

Kirkendall, R. Private communication. U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD. Conversation with the author, February 1984.

Robbins, F. W. Private communication. U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD. Conversations with author, October 1981 and subsequently.

Sassé, R. A. Private communication. U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD. Conversations with the author, February–March 1991.

Sassé, R. A., H. E. Holmes, W. P. Aungst, J. O. Doali, R. E. Bowman, and D. Hansen. "Evaluation of Black Powder Produced by Indiana Army Ammunition Plant." BRL-TR-2596, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, October 1984.

Silsby, G. F., R. J. Roszak, and L. Giglio-Tos. "BRL's 50-mm High Pressure Powder Gun for Terminal Ballistic Testing - The First Year's Experience." ARBRL-MR-0326, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, January 1983.

White, K. J. Private communication. U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD. Conversations with the author, April 1981 and subsequently.

APPENDIX:

PROPELLANT DESCRIPTION SHEETS

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PROPELLANT DESCRIPTION SHEETS

Figures A-1–A-11 are copies of propellant description sheets (PDSs) for 7-perforation granular M30 propellants of interest to users of the 50-mm gun system. The PDSs describe the process by which the particular lots of propellant were manufactured and the chemistry, geometry, and other information about the finished product. The propellants having an average web size of nominally 0.032 in was mass-produced for use in service ammunition. There is also some M30 propellant with a web size as small as 0.029 in, which was produced in quantity for ammunition developmental purposes. All smaller web sizes were custom-produced for various Aberdeen Proving Ground users.

For these smaller granulations, the product geometry is often far from ideal. The production process was essentially one step in a propellant production development program, done on a best-efforts basis. A die geometry was selected based on experience. In some instances, for economy, on-hand die components close to the desired size were used. The propellant was made, measured, shipped, and used without any iteration on die design. Nonetheless, within the broad strictures imposed by terminal ballistics test requirements, the propellants seem to behave as though they have ideal geometry for the average web size measured. The propellant geometries sought were 0.012-, 0.015-, 0.018-, and 0.025-in web. Table A-1 lists the nominal geometries produced. Table entries duplicating a previous line are not repeated.

Table A-1. Summary of Nominal 7-perf. M30 Granular Propellant Geometries for Appended PDSs

Nom. Web (in)	Avg. Web (in)	Length (in)	Outer Dia. (in)	Perf. Dia. (in)	Application	Year Mfg.	Lot(s)
0.012	0.012	0.186	0.086	0.012	Custom manufacture	1986	RAD-PE-771-4
	0.013	0.180	0.081	0.010		1973	RAD-E-29
0.015	0.015	0.206	0.094	0.012	Custom manufacture	1973	RAD-E-30
	0.016	0.232	0.105	0.015		1973	RAD-E-31
		0.208	0.094	0.010		1994	MEI-153-001
0.018	0.018	0.231	0.105	0.011	Custom manufacture	1984	RAD-PE-771-1
						1985	RAD-PE-771-2
						1986	RAD-PE-771-3
0.025	0.022	0.231	0.126	0.014	Custom manufacture	1992	RAD-PD-086-1
0.032	0.032	0.400	0.169	0.014	f/CTG TPDS-T M724E1, f/105-mm M68 Gun	1974 1975	RAD-69291 RAD-69315

NOTE: All manufactured at the Radford Army Ammunition Plant, Radford, VA. Information Source: Graham Silsby, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD (410) 278-6012.

PROPELLANT DESCRIPTION SHEET

REPORTS CONTROL SYMBOL
EXEMPT-PARA 7-2a
AR 335-15

COMPOSITION: M30, 7 Perf.	DA LOT NUMBER: RAD-PE-771-4
SPECIFICATION: SMCRA-EN dtd. 2-21-85, MIL-P-63515 **	PACKED AMOUNT: 4,105 lbs.
MFG AT: Radford Army Ammunition Plant, Radford, VA	CONTRACT NUMBER: DAAA09-86-A-0003

NITROCELLULOSE

ACCEPTED BLEND NUMBERS	NITROGEN CONTENT	KI STARCH (65.5°C)	STABILITY (134.5°C)
B32,885	MAX ____ %	____ MIN	____ MIN
	MIN ____ %	____ MIN	____ MIN
	AVG 12.64 %	45+ MIN	30+ MIN
			EXPLOSION HR

MANUFACTURE OF SOLVENT PROPELLANT

0.22 POUNDS SOLVENT PER POUND NC/DRY WEIGHT INGREDIENTS CONSISTING OF 60 POUNDS ALCOHOL AND 40 POUNDS acetone PER 100 POUNDS SOLVENT PERCENTAGE REMIX TO WHOLE 20-24

TEMPERATURES ° FROM	TO	PROCESS—SOLVENT RECOVERY AND DRYING	TIME DAYS	HOURS
Ambient	Ambient	Load FAD at Ambient		
Ambient	81°	Increase and hold temperature to 81°F ± 5°F		24
81°	140°	Increase temperature 5° per hour to 140°F		12
140°	140°	Hold on temperature		40
140°	Ambient	Cool down for sampling		

TESTS OF FINISHED PROPELLANT

PROPELLANT COMPOSITION: CONSTITUENT	PERCENT FORMULA	PERCENT TOLERANCE	PERCENT MEASURED	STABILITY AND PHYSICAL TESTS	FORMULA	ACTUAL
Nitrocellulose	28.00	±1.30	28.25	HEAT TEST 120°C	No CC 1hr	No CC 1hr
Nitroglycerin	22.50	±1.00	22.70	No Fumes	NF 1 hr.	NF 1 hr.
Nitroguanidine	47.70	±1.00	47.24	FORM OF PROPELLANT	Cyl.	Cyl.
Ethyl Centralite	1.50	±0.10	1.41	No. Perfs	7	7
Cryolite	0.30	±0.10	0.40			
				Abs. Dens (gm/cc)	N/A	1.66
TOTAL	100.00		100.00			
				HOE (cal/gm)	979.08***	974.4
Total Volatiles	0.20	max	0.09			
Graphite	0.10	nom	0.07	Bulk Dens.(gm/cc)	N/A	0.948

CLOSED BOMB

	LOT NUMBER	TEMP °F	RELATIVE QUICKNESS	RELATIVE FORCE
TEST	RADPE 771-4	+90	141.05*	108.46
	RADPE 771-4	+145	142.91*	108.73
	RADPE 771-4	-40	136.89*	106.35
STANDARD	CIL 3331	+90	100.00%	100.00%

REMARKS
Loaded in 200cc closed bomb at .2 loading density.

* Note: Check RQ's before firing

PROPELLANT DIMENSIONS (inches)

	SPECIFICATION	DIE	FINISHED	Mean Variation in % of Mean Dimensions: SPEC	ACTUAL
LENGTH (L)	0.181 nom		0.1875		
DIAMETER (D)	0.084	0.087	0.0859		
PERF. DIA. (d)	0.012	0.014	0.0118		
Web Avg.	0.012	0.014	0.0125		
Outer	0.012	0.0045	0.0169		
Inner	0.012	0.023	0.0081		
Web Difference /Std. Dev. in % of Web Avg.					
L:D			2.18		
D:d			7.29		

DATES
- PACKED 8/24/86
- SAMPLED 8/24/86
- TEST FINISHED 9/11/86
- OFFERED
- DESCRIPTION SHEETS FORWARDED 01 Oct 86

TYPE OF PACKING CONTAINER: FIBER DRUMS: 25 @ 160 lbs per, 1 @ 105 lbs. per

REMARKS Propellant manufactured with 1975 Nitroguanidine and RAAP Nitroglycerin.
** Chemical composition from MIL-P-63515. Web dimensions from SMCRA-EN dtd 2-21-85. Other physical dimensions were determined by Hercules from RAD-E-29 referenced in SMCRA-EN dtd 2-21-85. *** HOE based on actual composition.

THIS LOT MEETS SPECIFICATION REQUIREMENTS.

SIGNATURE OF CONTRACTOR'S REPRESENTATIVE	SIGNATURE OF GOVERNMENT QUALITY ASSURANCE REPRESENTATIVE
Elizabeth Rivenbark (signed) Elizabeth Rivenbark	(signature)

ARRCOM FORM 2148 10 AUG 77

771-4

Figure A-1. Propellant description sheet RAD-PE-771-4.

PROPELLANT DESCRIPTION SHEET

U.S. Army Lot No. RAD-E-29 of 1973 Composition No. M30, MP f/105mm M68, 35mm Scaled

Manufactured at RADFORD ARMY AMMUNITION PLANT, RADFORD, VA. Packed Amount 272 Pounds

Contract No. DAAA09-71-C-0329 Date 6-30-71 Specification No. COR Letter SMURO-IE dated 2 March 1973

NITROCELLULOSE

Accepted Blend Numbers		Nitrogen Content	KI Starch (65.5°C)	Stability (134.5°C)
A-35,332	Maximum	%	Mins	Mins
	Minimum	%	Mins	Mins
	Average	12.54 %	45+ Mins	30+ Mins
				Explosion Mins

MANUFACTURE OF PROPELLANT

22 Pounds Solvent per Pound ~~C~~/Dry Weight Ingredients Consisting of 60 Pounds Alcohol and 40 Pounds Acetone per 100 Pounds Solvent

Percentage Remix to Whole 10

Temperatures °F From	To	PROCESS-SOLVENT RECOVERY AND DRYING	Time Days	Hours
		Load Forced Air Dry at Ambient Temperature		
Ambient	140	Increase Temperature 5°F Per Hour		
140	140	Hold at Temperature		24

TESTS OF FINISHED PROPELLANT

Propellant Composition Constituent	Percent Formula *	Percent Tolerance *	Percent Measured	Stability and Physical Tests	Formula *	Actual
Nitrocellulose	28.00	±1.30	29.17	Heat Test, SP, 120°C	No CC 40'	60'
Nitroglycerin	22.50	±1.00	21.60	No Fumes		60'
Nitroguanidine	47.70	±1.00	47.42	Form of Propellant		Cyld.
Ethyl Centralite	1.50	±0.10	1.53	No. of Perforations		7
Cryolite	0.30	±0.10	0.28			
TOTAL			100.00			
Total Volatiles	0.50	Max.	0.21			
Graphite Glaze	0.2	Max.	0.09			

CLOSED BOMB

	Lot Number	Temp °F	Relative Quickness	Relative Force
Test				
Standard			100.00%	100.00%
Remarks				

PROPELLANT DIMENSIONS (inches)

	Specification	Die	Finished	Mean Variation in % of Mean Dimensions Spec. *	Actual
Length (L)		0.1810	0.1798	6.25Max.	1.38
Diameter (D)		0.0870	0.0810	6.25Max.	4.09
Perf. Dia (d)		0.0140	0.0105		
Web Inner		0.0160	0.0073		
Web Outer		0.0065	0.0183		
Web Avg.		0.0112	0.0128		
Nom. Avg. Web	0.0132				
Web Difference/Std. Dev. in % of Web Average	15 Max.*		86		
L/D	2.10 to 2.50*		2.22		
D/d	5.0 to 15*		7.7		

DATES	
Packed	10/5/73
Sampled	10/5/73
Test Finished	10/17/73
Offered	10/18/73
Description Sheets Forwarded	10/25/73

Type of Packing Container Fiber Drums per MIL-STD-652B.

Remarks *Limits from MIL-STD-652B w/EO PA-56070-2 and EO PA-57189-2 shown for information only. Propellant produced on a best effort basis in accordance with referenced COR letter.

Contractor's Representative: H. E. BISHOP H. E. Bishop 10-19-73

Government Quality Assurance Representative: JAMES E. BLAND James E. Bland

RFU FORM 1047R MARCH 1971

Figure A-2. Propellant description sheet RAD-E-29.

PROPELLANT DESCRIPTION SHEET

U.S. Army Lot No. RAD-E-30 of 19 73 Composition No. M30, MP f/105mm M68, 35mm Scaled

Manufactured at RADFORD ARMY AMMUNITION PLANT, RADFORD, VA. Packed Amount 269 Pounds

Contract No DAAA09-71-C-0329 Date 6-30-71 Specification No COR Letter SMURO-IE dated 2 March 1973

NITROCELLULOSE

Accepted Blend Numbers		Nitrogen Content	KI Starch (65.5°C)	Stability (134.5°C)
A-35,332	Maximum	%	Mins	Mins
	Minimum	%	Mins	Mins
	Average	12.54 %	45+ Mins	30+ Mins
				Explosion Mins

MANUFACTURE OF PROPELLANT

0.22 Pounds Solvent per Pound NC/Dry Weight Ingredients Consisting of 60 Pounds Alcohol and 40 Pounds Acetone per 100 Pounds Solvent.

Percentage Remix to Whole 10

Temperatures °F From	To	PROCESS-SOLVENT RECOVERY AND DRYING	Time Days	Hours
		Load Forced Air Dry at Ambient Temperature		
Ambient	140	Increase Temperature 5°F Per Hour		
140	140	Hold at Temperature		24

TESTS OF FINISHED PROPELLANT

Propellant Composition Constituent	Percent Formula *	Percent Tolerance *	Percent Measured	Stability and Physical Tests	Formula *	Actual
Nitrocellulose	28.00	±1.30	28.48	Heat Test, SP, 120°C	No CC 40'	60'
Nitroglycerin	22.50	±1.00	22.81	No Fumes		60'
Nitroguanidine	47.70	±1.00	46.90	Form of Propellant		Cyld.
Ethyl Centralite	1.50	±0.10	1.53	No. of Perforations		7
Cryolite	0.30	±0.10	0.28			
TOTAL			100.00			
Total Volatiles	0.50	Max.	0.27			
Graphite Glaze	0.2	Max.	0.08			

CLOSED BOMB

	Lot Number	Temp °F	Relative Quickness	Relative Force
Test				
Standard			100.00%	100.00%
Remarks				

PROPELLANT DIMENSIONS (inches)

	Specification	Die	Finished	Mean Variation in % of Mean Dimensions Spec*	Actual
Length (L)		0.2070	0.2065	6.25Max.	1.74
Diameter (D)		0.0990	0.0943	6.25Max.	2.60
Perf. Dia. (d)		0.0160	0.0123		
Web Inner		0.0205	0.0096		
Web Outer		0.0085	0.0198		
Web Avg.		0.0142	0.0147		
Nom. Avg. Web	0.0152				
Web Difference/Std. Dev in % of Web Average	15 Max.*		70		
L/D	2.10 to 2.50*		2.19		
D/d	5.0 to 15*		7.6		

DATES	
Packed	10/5/73
Sampled	10/5/73
Test Finished	10/17/73
Offered	10/18/73
Description Sheets Forwarded	10/25/73

Type of Packing Container Fiber Drums per MIL-STD-652B.

Remarks

*Limits from MIL-STD-652B w/EO PA-56070-2 and EO PA-57189-2 shown for information only. Propellant produced on a best effort basis in accordance with referenced COR letter.

Contractor's Representative H. E. BISHOP H. E. Bishop 10-19-73

Government Quality Assurance Representative JAMES E. BLAND J. E. Bland

SMU FORM 1047A MARCH 1971

Figure A-3. Propellant description sheet RAD-E-30.

PROPELLANT DESCRIPTION SHEET

U S Army Lot No. RAD-E-31 of 19 73 Composition No. M30, MP f/105mm M68, 35mm Scaled

Manufactured at RADFORD ARMY AMMUNITION PLANT, RADFORD, VA. Packed Amount 291 Pounds

Contract No DAAA09-71-C-0329 Date 6-30-71 Specification No COR Letter SMURO-IE dated 2 March 1973

NITROCELLULOSE

Accepted Blend Numbers	Nitrogen Content	KI Starch (65.5°C)	Stability (134.5°C)
A-35,332	Maximum %	Mins	Mins
	Minimum %	Mins	Mins
	Average 12.54 %	45+ Mins	30+ Mins
			Explosion Mins

MANUFACTURE OF PROPELLANT

0.22 Pounds Solvent per Pound ~~NC~~ Dry Weight Ingredients Consisting of 60 Pounds Alcohol and 40 Pounds Acetone per 100 Pounds Solvent.

Percentage Remix to Whole 10

Temperatures °F From	To	Process-Solvent Recovery and Drying	Time Days	Hours
		Load Forced Air Dry at Ambient Temperature		
Ambient	140	Increase Temperature 5°F Per Hour		
140	140	Hold at Temperature		24

TESTS OF FINISHED PROPELLANT

Propellant Composition Constituent	Percent Formula *	Percent Tolerance *	Percent Measured	Stability and Physical Tests	Formula *	Actual
Nitrocellulose	28.00	±1.30	28.30	Heat Test, SP, 120°C	No CC 40'	60'
Nitroglycerin	22.50	±1.00	22.55	No Fumes		60'
Nitroguanidine	47.70	±1.00	47.33	Form of Propellant		Cyld.
Ethyl Centralite	1.50	±0.10	1.54	No. of Perforations		7
Cryolite	0.30	±0.10	0.28			
Total			100.00			
Total Volatiles	0.50	Max.	0.28			
Graphite Glaze	0.2	Max.	0.07			

CLOSED BOMB

	Lot Number	Temp °F	Relative Quickness	Relative Force
Test				
Standard			100.00%	100.00%
Remarks				

PROPELLANT DIMENSIONS (inches)

	Specification	Dry	Finished	Mean Variation in % of Mean Dimensions Spec. *	Actual
Length (L)		0.2330	0.2321	6.25 Max.	1.92
Diameter (D)		0.0112	0.1048	6.25 Max.	3.37
Perf. Dia. (d)		0.0180	0.0147		
Web Inner		0.0174	0.0091		
Web Outer		0.0115	0.0220		
Web Avg.		0.0145	0.0156		
Nom. Avg. Web	0.0172				
Web Difference/Std. Dev. in % of Web Average	15 Max.*		82		
L/D	2.10 to 2.50*		2.21		
D/d	5.0 to 15*		7.1		

DATES

Packed 10/5/73

Sampled 10/5/73

Test Finished 10/26/73

Offered 10/26/73

Description Sheets Forwarded 10/31/73

Type of Packing Container Fiber Drums per MIL-STD-652B.

Remarks *Limits from MIL-STD-652B w/EO PA-56070-2 and EO PA-57189-2 shown for information only. Propellant produced on a best effort basis in accordance with referenced COR letter.

Contractor's Representative H. E. BISHOP H E Bishop 10-26-73

Government Quality Assurance Representative JAMES E. BLAND James E Bland

AMU FORM 1047R MARCH 1971

Figure A-4. Propellant description sheet RAD-E-31.

PROPELLANT DESCRIPTION SHEET

REPORTS CONTROL SYMBOL	EXEMPT-PARA-7-2a AR 335-15
COMPOSITION: M30, MP f 105/mm M68, 35 mm Scaled Propellant	DA LOT NUMBER: MEI-153-001
SPECIFICATION: AMSMC-PAI-G/TEAM E (R) TWX dated 12-29-93	PACKED AMOUNT: 700 POUNDS
MFG. AT: RADFORD ARMY AMMUNITION PLANT, RADFORD, VA	CONTRACT NUMBER CLIN NUMBER W1-4-AOB99-01-MI-FK: DAAA09-91-Z-0001 PRON NUMBER 3091AA

NITROCELLULOSE

ACCEPTED BLEND NUMBERS	NITROGEN CONTENT	KI STARCH (65.5 °C)	STABILITY (134.5 °C)
B-34516	MAX ____ %	____ MIN	____ MIN
	MIN ____ %	____ MIN	____ MIN
	AVG. 12.63 %	45+ MIN	30+ MIN
			EXPLOSION __ HR.

MANUFACTURE OF SOLVENT PROPELLANT

.22 POUNDS OF SOLVENT PER POUND DRY WEIGHT INGREDIENTS CONSISTING OF 60.0 POUNDS OF ALCOHOL AND 40.0 POUNDS ACETONE PER 100 POUNDS SOLVENT PERCENTAGE REMIX TO WHOLE

TEMPERATURES * FROM	TO	PROCESS-SOLVENT RECOVERY AND DRYING	TIME DAYS	HOURS
AMBIENT	AMBIENT	LOAD FORCED AIR DRY AT AMBIENT		
AMBIENT	140°F	INCREASE TEMPERATURE 5°F PER HOUR		
140°F	140°F	MAINTAIN TEMPERATURE AT 140°F		32

TESTS OF FINISHED PROPELLANT

PROPELLANT COMPOSITION CONSTITUENT	PERCENT FORMULA	PERCENT TOLERANCE	PERCENT MEASURED	STABILITY AND PHYSICAL TESTS	FORMULA	ACTUAL
				HEAT TEST @ 120°C	NO CC 40'	CC 60'+
NITROCELLULOSE	28.0	± 1.3	28.69	NO FUMES	NF 1 HR	NF 1 HR
NITROGLYCERIN	22.5	± 1.0	22.56	FORM OF PROPELLANT	CYLINDRICAL	CYLINDRICAL
NITROGUANIDINE	47.5	± 1.0	46.86	NUMBER OF PERFS	7	7
ETHYL CENTRALITE	1.5	± 0.1	1.49	HOE, CAL/G	INFO ONLY	973.0
CRYOLITE	0.3	± 0.1	0.29	ABS. DENSITY, G/CC		1.66
GRAPHITE	0.2	MAX.	0.11	BULK DENSITY		
TOTAL	100.00		100.00	lb/cu.ft		
TOTAL VOLATILES	0.5	MAX.	0.21	M456 Cartridge Case	63.0 nom	64.42

CLOSED BOMB

TEST	LOT NUMBER	TEMP °F	RELATIVE QUICKNESS	RELATIVE FORCE
STANDARD				

REMARKS

NO BALLISTIC REQUIREMENTS

PROPELLANT DIMENSIONS (Inches)

	SPECIFICATION	DIE	FINISHED	UNIFORMITY BY MEAN DIMENSIONS SPEC.	ACTUAL
LENGTH(L)	0.2065	0.207	0.2078	*6.25 MAX	2.85
DIAMETER(D).	0.094	0.10	0.0935	*6.25 MAX	2.71
PERF. DIA.(d)	0.016	0.016	0.0098		
INNER WEB		0.019	0.0157		
OUTER WEB		0.007	0.0162		
AVERAGE WEB		0.013	0.0160		
L:D	* 2.1 to 2.5		2.22		
D:d	* 5.0 to 15.0		9.52		

DATES	
PACKED	4/9/94
SAMPLED	4/9/94
TEST FINISHED	4/25/94
OFFERED	5/04/94
DESCRIPTION SHEETS FORWARDED	5/04/94

TYPE OF PACKING CONTAINER FIBER DRUM - 4 @ 150 pounds and 1 @ 100 pounds

REMARKS

* Limits from MIL-STD-652D Notice 6 dtd 28 April 1990 shown for information only. Propellant produced on a best effort basis.

THIS LOT MEETS ALL CHEMICAL & PHYSICAL REQUIREMENTS OF THE APPLICABLE SPECIFICATION.

SIGNATURE OF CONTRACTOR'S REPRESENTATIVE	SIGNATURE OF GOVERNMENT QUALITY ASSURANCE REPRESENTATIVE
James R. Marconnet	

ARRCOM FORM 214R 10 AUG 77

Figure A-5. Propellant description sheet MEI-153-001.

PROPELLANT DESCRIPTION SHEET

REPORTS CONTROL SYMBOL: EXEMPT-PARA 7-2a AR 335-15

COMPOSITION: M30 Propellant	DA LOT NUMBER: RAD-PE-771-1
SPECIFICATION: COR Letter SMCRA-EN dated 9/7/83	PACKED AMOUNT: 690 lbs.
MFG AT: RADFORD ARMY AMMUNITION PLANT, RADFORD, VA.	CONTRACT NUMBER: DAAA09-77-C-4007

NITROCELLULOSE

ACCEPTED BLEND NUMBERS	NITROGEN CONTENT	KI STARCH (65.5°C)	STABILITY (134.5°C)
B 31,355	MAX ___ %	___ MIN	___ MIN
	MIN ___ %	___ MIN	___ MIN
	AVG 12.64 %	45+ MIN	30+ MIN
			EXPLOSION ___ HR

MANUFACTURE OF SOLVENT PROPELLANT

0.25 POUNDS SOLVENT PER POUND NC/DRY WEIGHT INGREDIENTS CONSISTING OF 60 POUNDS ALCOHOL AND 40 POUNDS acetone PER 100 POUNDS SOLVENT PERCENTAGE REMIX TO WHOLE 0

TEMPERATURES °F FROM	TO	PROCESS—SOLVENT RECOVERY AND DRYING	TIME DAYS	HOURS
ambient	80	Ambient hold		24
80	140	Increase at 5°F per hour		12
140	140	Hold at temperature		40
140	ambient	Cool down for processing		

TESTS OF FINISHED PROPELLANT

PROPELLANT COMPOSITION CONSTITUENT	PERCENT FORMULA	PERCENT TOLERANCE	PERCENT MEASURED	STABILITY AND PHYSICAL TESTS	FORMULA	ACTUAL
Nitrocellulose	28.0	± 1.30	27.85	HEAT TEST	40'	cc 60'+
Nitroglycerine	22.50	± 1.00	23.02	no fumes	60'	NF 1 hr
Nitroguanidine	47.70	± 1.00	47.31	FORM OF PROPELLANT	cyl	cyl
Ethyl Centralite	1.50	± 0.10	1.50	No. of perfs	7	7
Cryolite	0.30	± 0.10	0.32	Abs. Dens. g/cc		1.68
TOTAL	100.00		100.00			
Total Volatiles	0.30	max	0.16			
Graphite	0.20	max	0.17			

CLOSED BOMB

	LOT NUMBER	TEMP °F	RELATIVE QUICKNESS	RELATIVE FORCE
TEST				
STANDARD			100.00%	100.00%

REMARKS

PROPELLANT DIMENSIONS (inches)

	SPECIFICATION	DIE	FINISHED	MEAN VAR. IN % of Mean Dimensions SPEC.	ACTUAL
LENGTH (L)	0.230	0.230	0.230	n/a	n/a
DIAMETER (D)	0.105	0.112	0.107	n/a	n/a
PERF. DIA. (d)	0.0113	0.018	0.0117		
Web ave.	0.015	0.0147	0.018		
Web Difference /Std. Dev. in % of Web Avg.	n/a	n/a	n/a		
L:D	2.19	n/a	2.15		
D:d	9.29	n/a	9.15		

DATES	
PACKED	2/2/84
SAMPLED	2/2/84
TEST FINISHED	3/12/84
OFFERED	
DESCRIPTION SHEETS FORWARDED	06 Apr 84

TYPE OF PACKING CONTAINER: FIBER DRUMS 652D: 4 @ 150 lbs.net; 1 @ 90 lbs. net.

REMARKS

SIGNATURE OF CONTRACTOR'S REPRESENTATIVE	SIGNATURE OF GOVERNMENT QUALITY ASSURANCE REPRESENTATIVE
/s/ J. C. COKER	/s/ J. E. BLAND

ARRCOM FORM 2148 10 AUG 77

SEQUENCE No. 373

Figure A-6. Propellant description sheet RAD-PE-771-1.

PROPELLANT DESCRIPTION SHEET

REPORTS CONTROL SYMBOL
EXEMPT-PARA 7-2a
AR 335-15

COMPOSITION: M30 Propellant	DA LOT NUMBER: RAD-PE-771-2
SPECIFICATION: Mil-P-63105 COR ltr SMCRA-EN dtd 2-2-84 with SOW dtd 1-19-84	PACKED AMOUNT: 700 lbs.
MFG AT: RADFORD ARMY AMMUNITION PLANT, RADFORD, VA.	CONTRACT NUMBER: DAAA09-77-C-4007

NITROCELLULOSE

ACCEPTED BLEND NUMBERS	NITROGEN CONTENT	KI STARCH (65.5°C)	STABILITY (134.5°C)
B32,307	MAX ____ %	____ MIN	____ MIN
	MIN ____ %	____ MIN	____ MIN
	AVG 12.62 %	45+ MIN	30+ MIN
			EXPLOSION ____ HR

MANUFACTURE OF SOLVENT PROPELLANT

.22 POUNDS SOLVENT PER POUND NC/DRY WEIGHT INGREDIENTS CONSISTING OF 60 POUNDS ALCOHOL AND 40 POUNDS acetone PER 100 POUNDS SOLVENT PERCENTAGE REMIX TO WHOLE

TEMPERATURES °F FROM	TEMPERATURES °F TO	PROCESS-SOLVENT RECOVERY AND DRYING	TIME DAYS	TIME HOURS
Ambient	Ambient	Load at Ambient		
Ambient	81	Hold at 81° for 24 hrs.		24
81	140	Build temperature to 140°F @ 5°F per hour		12
140	140	Hold at 140° for 40 hours		40
140	Ambient	Cool down for sampling		

TESTS OF FINISHED PROPELLANT

PROPELLANT COMPOSITION CONSTITUENT	PERCENT FORMULA	PERCENT TOLERANCE	PERCENT MEASURED	STABILITY AND PHYSICAL TESTS	FORMULA	ACTUAL
Nitrocellulose	28.00	± 1.30	28.00	HEAT TEST 120°	CC 60	CC 60+
Nitroglycerin	22.50	± 1.00	22.61	No Fumes	NF 1 hr.	NF 1 hr
Nitroguanidine	47.70	± 1.00	47.46	FORM OF PROPELLANT	CYL	CYL
Ethyl Centralite	1.50	± 0.10	1.57	No. of Perfs.	7	7
Cryolite	0.30	± 0.10	0.36			
				Compressibility %	N/A	29.98
TOTAL	100.00		100.00	Abs.Dens.(gm/cc)	N/A	1.67
				HOE (cal/gm)	977.4	973.0
Total Volatiles	0.50	max	0.18			
Graphite	0.20	max	0.10			

CLOSED BOMB

	LOT NUMBER	TEMP °F	RELATIVE QUICKNESS	RELATIVE FORCE
TEST	RAD PE-771-2	90	*119.62	107.89
	RAD PE-771-2	145	*118.48	108.60
	RAD PE-771-2	-40	*120.15	107.02
STANDARD	CIL 3331	90	100.00%	100.00%

REMARKS
700cc closed bomb with
0.20 loading density.

* NOTE: Check RQ before firing.

PROPELLANT DIMENSIONS (inches)

	SPECIFICATION	DIE	FINISHED	of Mean Dimensions SPEC.	of Mean Dimensions ACTUAL
LENGTH (L)	0.230		0.230		
DIAMETER (D)	0.105	0.112	0.105		
PERF. DIA. (d)	0.012	0.016	0.012		
Web Avg.	0.018	0.015	0.018		
Inner	0.018	0.025	0.020		
Outer	0.018	0.005	0.016		
Web Difference /Std. Dev. in % of Web Avg.					
L:D	2.20		2.20		
D:d	8.53		8.55		

DATES	
PACKED	4/15/85
SAMPLED	4/15/85
TEST FINISHED	5-2-85
OFFERED	7-21-85
DESCRIPTION SHEETS FORWARDED	9 Sep 86

TYPE OF PACKING CONTAINER: FIBER DRUMS 652D: 4 @ 160 lbs. net; 1 @ 60 lbs. net.

REMARKS
HOE formula calculations based on "percent measured" results.

Propellant accepted as is per S.O.W. dtd 1-19-84.

THIS LOT MEETS SPECIFICATION REQUIREMENTS.

SIGNATURE OF CONTRACTOR'S REPRESENTATIVE	SIGNATURE OF GOVERNMENT QUALITY ASSURANCE REPRESENTATIVE
J.C. Coker JC Coker	Ronald L. Cromer

ARRCOM FORM 214R 10 AUG 77

Figure A-7. Propellant description sheet RAD-PE-771-2.

CNH

PROPELLANT DESCRIPTION SHEET

REPORTS CONTROL SYMBOL: EXEMPT-PARA 7-2a AR 335-15

COMPOSITION: M30 XM833	DA LOT NUMBER: RAD-PE-771-3
SPECIFICATION: SMCRA-EN Dated 5-13-86, MIL-P-63515 *	PACKED AMOUNT: 300 lbs
MFG AT: RADFORD ARMY AMMUNITION PLANT, RADFORD, VA.	CONTRACT NUMBER: DAAA-09-86-Z-0003

NITROCELLULOSE

ACCEPTED BLEND NUMBERS	NITROGEN CONTENT	KI STARCH (65.5°C)	STABILITY (134.5°C)
B32,777			
	MAX ____ %	____ MIN	____ MIN
	MIN ____ %	____ MIN	____ MIN
	AVG 12.53 %	45+ MIN	30+ MIN
			EXPLOSION ____ HR

MANUFACTURE OF SOLVENT PROPELLANT

0.22 POUNDS SOLVENT PER POUND NC/DRY WEIGHT INGREDIENTS CONSISTING OF 60 POUNDS ALCOHOL AND 40 POUNDS Acetone PER 100 POUNDS SOLVENT · PERCENTAGE REMIX TO WHOLE 20 - 24

PROCESS-SOLVENT RECOVERY AND DRYING

TEMPERATURES ° FROM	TEMPERATURES ° TO		TIME DAYS	TIME HOURS
Ambient	Ambient	Load FAD at Ambient		
Ambient	81°	Increase and hold temperature to 81°F ± 5°F		24
81°	140°	Increase temperature 5° per hour to 140°		12
140°	140°	Hold on temperature		40

TESTS OF FINISHED PROPELLANT

PROPELLANT COMPOSITION CONSTITUENT	PERCENT FORMULA	PERCENT TOLERANCE	PERCENT MEASURED	STABILITY AND PHYSICAL TESTS	FORMULA	ACTUAL
Nitrocellulose	28.00	± 1.30	28.45	HEAT TEST 120°C	No cc 40'	No cc60+
Nitroglycerin	22.50	± 1.00	22.86	No Fumes	NF 1 hr	NF 1 hr
Nitroguanidine	47.70	± 1.00	46.83	FORM OF PROPELLANT	Cvl	Cvl
Ethyl Centralite	1.50	± 0.10	1.56	No. of Perfs	7	7
Cryolite	0.30	± 0.10	0.30			
Total	100.00		100.00	HOE (cal/gm)	980.84**	969.5
Total Volatiles	0.20	Max	0.11	Abs.Dens.(g/cc)	N/A	1.676
Graphite	0.25	Max	0.06			
				Bulk Dens.(g/cc)	N/A	0.9444

CLOSED BOMB

	LOT NUMBER	TEMP °F	RELATIVE QUICKNESS	RELATIVE FORCE
TEST RAD	PE-771-3	+90	112.15	107.33
RAD	PE-771-3	+145	113.04	108.09
RAD	PE-771-3	-40	108.93	105.21
STANDARD	CIL 3331	+90	100.00%	100.00%

REMARKS

Tested in a 200cc closed bomb at 0.20 loading density.

PROPELLANT DIMENSIONS (INCHES)

	SPECIFICATION	DIE	FINISHED	SPEC. (of Mean Dimensions)	ACTUAL (of Mean Dimensions)
LENGTH (L)			0.2343		
DIAMETER (D)		0.112	0.1027		
PERF. DIA. (d)	0.012	0.018	0.0105		
Web Avg.	0.020 Nom		0.0180		
Inner	0.020 Nom		0.0212		
Outer	0.020 Nom		0.0149		
Web Difference /Std. Dev. in % of Web Avg.					
L/D			2.28		
D/d			9.77		

DATES

- PACKED: 6/24/86
- SAMPLED: 6/24/86
- TEST FINISHED: 7/24/86
- OFFERED:
- DESCRIPTION SHEETS FORWARDED: 13 Aug 86

TYPE OF PACKING CONTAINER: Fiber Drums: 652D: 3 @ 100 lb. Net

REMARKS

* Chemical composition from MIL-P-63515. Web dimensions from SMCRA-EN-dtd 5-13-85. Other physical dimensions were determined by Hercules from PD 771-1 & 2 referenced in SMCRA-EN-dtd 5-13-85. ** HOE based on actual composition. NO from CCI 1977-1979.

This lot meets specification requirements.

SIGNATURE OF CONTRACTOR'S REPRESENTATIVE	SIGNATURE OF GOVERNMENT QUALITY ASSURANCE REPRESENTATIVE
Elizabeth Rivenbark (signed) Elizabeth Rivenbark	Ronald M Boone

ARRCOM FORM 214R 10 AUG 77

ATTACHMENT I

Figure A-8. Propellant description sheet RAD-PE-771-3.

PROPELLANT DESCRIPTION SHEET

REPORTS CONTROL SYSTEM
EXEMPT PARA 7-2a
AR 335-15

COMPOSITION: PROPELLANT, M30, 7-PERF GRANULAR	LOT NUMBER: RAD-PD-086-1
SPECIFICATION: Letter from Order Release No. 376-9	PACKED AMOUNT: 792 pounds
UFACTURED: RADFORD ARMY AMMUNITION PLANT, RADFORD, VIRGINIA 24141	CONTRACT NUMBER: DAAA09-91-Z-0001

NITROCELLULOSE

Accepted Blend Numbers	Nitrogen Content	KI Starch (65.5°C)	STABILITY (134.5°C)
B834339	AVG 12.58%	45+ MINS	30+ MINS

MANUFACTURE OF SOLVENT PROPELLANT

0.22 POUNDS SOLVENT PER POUND DRY WEIGHT INGREDIENTS CONSISTING OF 60 POUNDS ALCOHOL AND 40 POUNDS ACETONE PER 100 POUNDS SOLVENT PERCENTAGE REMIX TO WHOLE 20%

TEMPERATURE, °F FROM	TO	PROCESS - DRYING	TIME DAYS	HOURS
50	70	BLOCK AT EXTRUSION		
110	130	EXTRUSION DIE		
50	70	FAD		24
125	135	FAD		24

TEST OF FINISHED PROPELLANT

PROPELLANT COMPOSITION Constituent	Percent Formula	Percent Tolerance	Percent Measured	STABILITY AND PHYSICAL TESTS Tests	Formula	Actual
Nitrocellulose	28.00	±1.30	28.24	Heat test @ 120°C	NCC 40'	CC 60'+
Nitroglycerin	22.50	±1.00	22.49	No fumes	NF 1 HR	NF 1 HR
Nitroguanidine	47.70	±1.00	47.53	Form of Propellant	cyl	cyl
Ethyl Centralite	1.50	±0.10	1.48	Number of Perfs	7	7
Cryolite	0.30	±0.10	0.26	Taliani		
Total	100.00		100.00	Slope at 100 mm Hg	N/A	N/A
Graphite	0.20	MAX	0.10	Bulk Density (lb/ft^3)	INFO	64.94
Total Volatiles	0.50	MAX	0.08	HOE, cal./g	INFO	970.0
				Absolute Density g/cc	INFO	1.65

CLOSED BOMB

	Lot Number	Temp °F	Relative Quickness	Relative Force
TEST				
	PDI-086-1	+90	163.3	101.7
	PDI-086-1	+145	163.3	102.8
	PDI-086-1	-40	163.2	100.3
STD	69903	+90	100.0%	100.0%

REMARKS:

1. Fired in a 200CC closed bomb at 0.193 LD.
2. Average grain weight from a sample of 100 grains: 7.29 grams

PROPELLANT DIMENSIONS (INCHES)

	SPEC	DIE	FINISHED	Uniformity by Std Deviation, % SPEC	ACTUAL
LENGTH (L)	0.230 NOM	---	0.231	N/A	N/A
DIA. (D)	0.136 NOM	0.138	0.126	N/A	N/A
PERF. (D)	0.012 NOM	0.018	0.014	Dates	
WEB (AVG)	0.025 NOM	0.0205	0.022	PACKED 1-92	
INNER	0.025 NOM	0.029	0.025	SAMPLED 1-92	
OUTER	0.025 NOM	0.012	0.018	TEST FINISHED 2-92	
WEB DIFF	15% MAX	---	-33.0	OFFERED 2-92	
L:D	1.69	---	1.84	DESCRIPTION SHEETS FORWARDED	
D:d	11.33	---	9.21		

TYPE OF PACKING CONTAINER: 2IC FIBERBOARD DRUMS, (15) 50 LB/DRUMS, (1) 42 LB/DRUMS

REMARKS: THIS LOT MEETS SPECIFICATION REQUIREMENTS WITH THE EXCEPTION OF WEB DIFFERENCE

SIGNATURE OF PROGRAM ENGINEER cbc N. G. WYER Alan Parrial	SIGNATURE OF GOVERNMENT QUALITY ASSURANCE REPRESENTATIVE

COM FORM 214R 10 AUG 77 DESC\086-

Figure A-9. Propellant description sheet RAD-PD-086-1.

COPY AVAIL

PROPELLANT DESCRIPTION SHEET

U.S. Army Lot No. RAD-69291 of 19 74 Composition No. M30, f/Ctg., TPDS-T, M724E1 f/105MM,M68

Manufactured at RADFORD ARMY AMMUNITION PLANT, RADFORD, VA. Packed Amount 317,265 pounds 58.75
Contract No. DAAA09-71-C-0529 Date 6-30-71 Specification No. MIL-P-46154

NITROCELLULOSE

ACCEPTED BLEND NUMBERS		Nitrogen Content	KI Starch (65.5°C)	Stability (134.5°C)
A-35,406; 408; 409; 410; 411; 412; 415	Maximum	12.63 %	Mins.	Mins.
	Minimum	12.52 %	Mins.	Mins.
	Average	12.58 %	45+ Mins.	30+ Mins.
				Explosion Mins.

MANUFACTURE OF PROPELLANT

0.22 Pounds Solvent per Pound XX/ Dry Weight Ingredients Consisting of 60 Pounds Alcohol and 40 Pounds Acetone per 100 Pounds Solvent.
Percentages Remis to Whole 10

TEMPERATURES °F From	To	PROCESS-SOLVENT RECOVERY AND DRYING	TIME Days	Hours
		Load Forced Air Dry at ambient temperature		
Ambient	140	Increase temperature 5°F per hour		
140	140	Hold at temperature		36

TESTS OF FINISHED PROPELLANT

PROPELLANT COMPOSITION Constituent	Percent Formula	Percent Tolerance	Percent Measured	STABILITY AND PHYSICAL TESTS	Formula	Actual
Nitrocellulose	28.00	±1.30	28.00	Heat Test, SP,120°C	No CC 40'	CC 60'+
Nitroglycerin	22.50	±1.00	22.52	No Fumes		60'
Nitroguanidine	47.70	±1.00	47.59	Form of Propellant		Cyld.
Ethyl Centralite	1.50	±0.10	1.55	No. of Perforations		7
Cryolite	0.30	±0.10	0.34			
TOTAL	100.00		100.00			
Total Volatiles	0.50	Max.	0.18			
Graphite Glaze	0.2	Max.	0.15			

CLOSED BOMB

	Lot Number	Temp °F	Relative Quickness	Relative Force
Test				
	RAD-69291	+90	96.82	99.58
Standard	E-32	+90	100.00%	100.00%

Remarks
FIRED IN ACCORDANCE WITH MIL-STD-286B, METHOD 801.1.1 IN A NOMINAL SIZE 200CC CLOSED BOMB. TEST FOR INFORMATIONAL PURPOSES ONLY.

PROPELLANT DIMENSIONS (inches)

	Specification	Die	Finished	Mean Variation in % of Mean Dimensions Spec.	Actual
Length (L)		0.395	0.4024	6.25 Max.	1.20
Diameter (D)		0.192	0.1679	6.25 Max.	2.52
Perf Dia (d)		0.020	0.0139		
Web					
Inner		0.0355	0.0315		
Outer		0.0305	0.0332		
Average	0.033 Nom.	0.0330	0.0324		
Web Difference/Std Dev. in % of Web Average	15 Max.		5.1		
L/D	2.10 to 2.50		2.40		
D/d	5.0 to 15		12.1		

DATES

Packed	6/8/74
Sampled	6/8/74
Test Finished	6/17/74
Offered	6/18/74
Description Sheets Forwarded	6/19/74

Type of Packing Container Fiber Drums per MIL-STD-652B.
Remarks This lot meets all requirements of the applicable specifications.

Contractor's Representative
J. K. MULLER J K Muller

Government Quality Assurance Representative
JAMES E. BLAND J E B Simmons

Figure A-10. Propellant description sheet RAD-69291.

PROPELLANT DESCRIPTION SHEET

U.S. Army Lot No. RAD-69315 of 19 75 Composition No. M30, f/Ctg., TPDS-T, M724E1 f/105MM.M68

Manufactured at RADFORD ARMY AMMUNITION PLANT, RADFORD, VA. Packed Amount 310,545 Pounds

Contract No. DAAA09-71-C-0329 Date 6-30-71 Specification No. MIL-P-48154

NITROCELLULOSE

ACCEPTED BLEND NUMBERS

A-35,475; 35,476, 35,477, 35,478, 35,482

	Nitrogen Content	KI Starch (65.5°C)	Stability (134.5°C)
Maximum	12.61 %	Mins	Mins
Minimum	12.51 %	Mins	Mins
Average	12.54 %	45+ Mins	30 Mins
Explosion			Mins

MANUFACTURE OF PROPELLANT

0.22 Pounds Solvent per Pound XX/Dry Weight Ingredients Consisting of 60 Pounds Alcohol and 40 Pounds Acetone per 100 Pounds Solvent.

Percentage Remix to Whole 10

Temperatures °F From	To	PROCESS-SOLVENT RECOVERY AND DRYING	Time Days	Hours
		Load Forced Air Dry at ambient temperature		
Ambient	140	Increase temperature 5°F per hour		
140	140	Hold at temperature		36

TESTS OF FINISHED PROPELLANT

PROPELLANT COMPOSITION Constituent	Percent Formula	Percent Tolerance	Percent Measured	STABILITY AND PHYSICAL TESTS	Formula	Actual
Nitrocellulose	28.00	±1.30	28.77	Heat Tests, SP,120°C	No CC 40'	CC 50'
Nitroglycerin	22.50	±1.00	22.26	No Fumes		NF 60'
Nitroguanidine	47.70	±1.00	47.15	Form of Propellant		Cyld.
Ethyl Centralite	1.50	±0.10	1.48	No. of Perforations		7
Cryolite	0.30	±0.10	0.34			
TOTAL	100.00		100.00			
Total Volatiles	0.50	Max.	0.19			
Graphite Glaze	0.2	Max.	0.16			

CLOSED BOMB

	Lot Number	Temp °F	Relative Quickness	Relative Force
Test				
	RAD-69315	+90	96.08	100.00
Standard	E-32	+90	100.00%	100.00%

Remarks: FIRED IN ACCORDANCE WITH MIL-STD-286B, METHOD 801.1.1 IN A NOMINAL SIZE 200CC CLOSED BOMB. TEST FOR INFORMATIONAL PURPOSES ONLY.

PROPELLANT DIMENSIONS (inches)

	Specification	Die	Finished	Mean Variation in % of Mean Dimensions Spec.	Actual
Length (L)		0.395	0.3977	6.25 Max.	2.40
Diameter (D)		0.192	0.1709	6.25 Max.	1.83
Perf. Dia. (d)		0.020	0.0153		
Web					
Inner		0.0355	0.0294		
Outer		0.0305	0.0340		
Average	0.033 Nom.	0.0330	0.0317		
Web Difference/Std. Dev. in % of Web Average	15 Max.		14.7		
L/D	2.10 to 2.50		2.33		
D/d	5.0 to 15		11.2		

DATES

Packed	2/1/75
Sampled	2/1/75
Test Finished	2/12/75
Offered	2/18/75
Description Sheets Forwarded	2-21-75

Type of Packing Container: Fiber Drums per MIL-STD-652C, with Notice 1.

Remarks: This lot meets all requirements of the applicable specifications.

Contractor's Representative: J. K. MULLER J K Muller

Government Quality Assurance Representative: JAMES E. BLAND James E. Bland

Figure A-11. Propellant description sheet RAD-69315.

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